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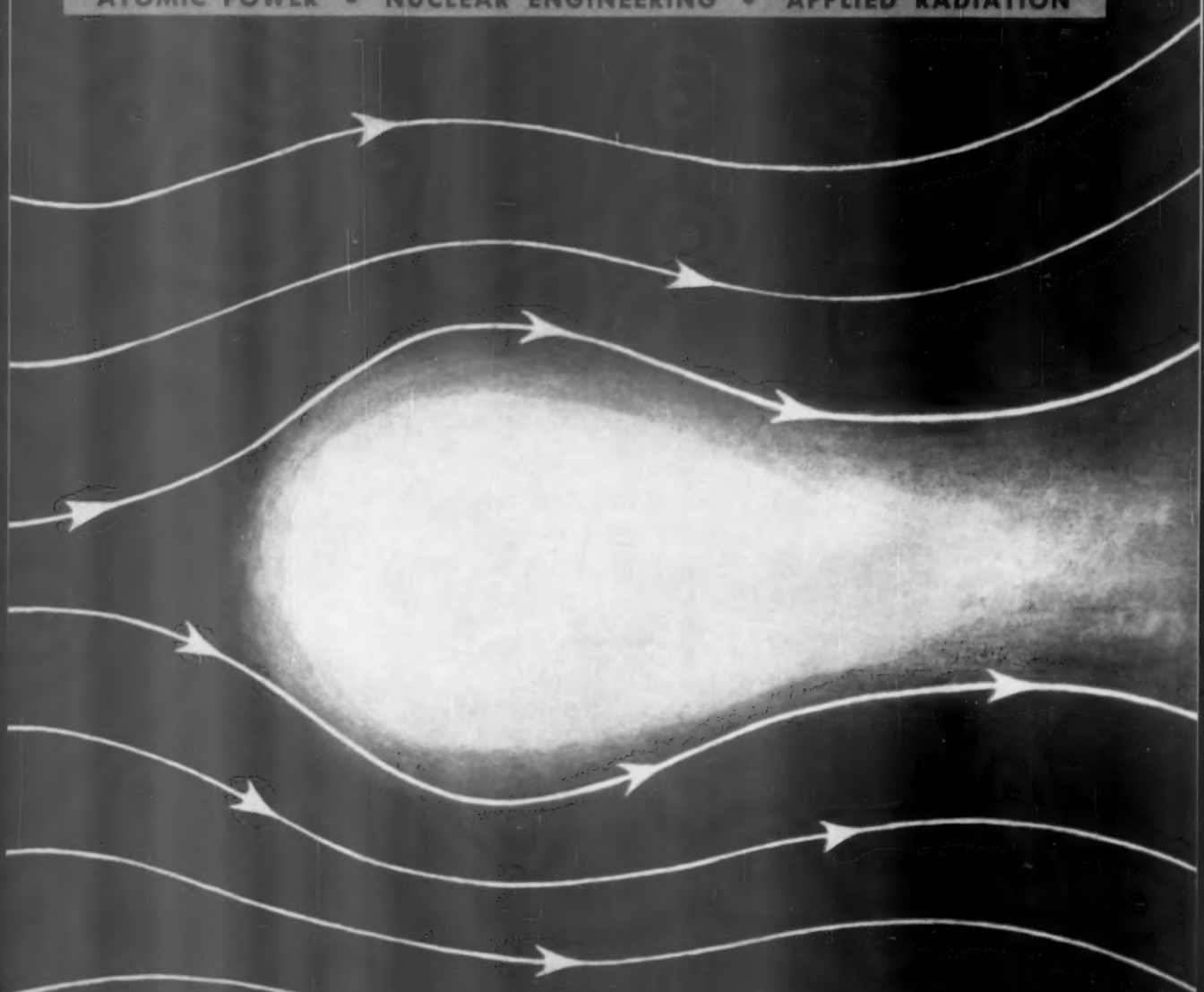
NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION



Plasma Interacts with
Magnetic Field to Produce
Electric Power Directly from Fission page 50

ENGINEERING LEADERSHIP
KEY TO ATOMIC PROGRESS

General Electric engineers to confirm Dresden reactor design data in critical assembly

At the General Electric Vallecitos Atomic Laboratory, design computations for the core of the 180,000-kw dual-cycle Dresden boiling water reactor will be confirmed with a critical experiment. General Electric is building the reactor for Commonwealth Edison Company's Dresden Nuclear Power Station.

In this nuclear mock-up of the Dresden core, engineers and physicists will study the critical geometry of the core lattice and various fuel and control rod arrangements. Future work will include studying the effect of temperature and voids on reactivity.

Performing critical experiments to confirm design data is an essential and cost-saving step in the design and development of nuclear reactors. Research such as this is another example of General Electric engineering leadership in the field of atomic energy. Atomic Power Equipment Department, General Electric Company, San Jose, California. 196-8

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About NUCLEONICS

1, 2, 3, 4, 5, 6, 7, 8, 9, 10. This month is a month of reminiscing for the staff of NUCLEONICS. As we get ready for our big tenth anniversary issue next month, we've been reliving the experiences of the first decade of our publishing life. In the process, we can't help but go over the happenings of the first decade of the civilian atomic energy industry. Both are intimately intertwined, a fact of which we are very proud.

And so we have entitled our special commemorative issue, "Nuclear Energy—1947–1957: A Decade of Progress, 1957–1967: A Decade of Promise." Although we shall, of course, devote a part of this issue to looking back over our collective shoulders, the bulk of the material will be a look ahead at the next decade in nuclear energy: what the problems are, the unknowns, what needs to happen, what is likely.

We divided the nucleonics field into about a dozen segments and invited top-flight specialists, including a number of Nobel laureates, to look into their crystal balls. In extending these invitations we said: "We would be honored if you would participate with us in this celebration, which we hope, in addition to being meaningful to us, will be symbolic of the great strides being made in achieving beneficent use of the atom."

We were flattered and pleased by the almost unanimously favorable responses we received. Now, at this writing, most of the manuscripts are in hand, and we must say that, although we've been living with this business over all these years, it's been fascinating to read in one collection of articles a comprehensive study of where the atom has been and where it may be going. This will not be a look at the nuclear world through rose-colored glasses but rather will be a sharp, realistic delineation of the problems ahead.

We hope you too will be with us next month to share in our celebration.

In addition to the look back that we'll be taking at the past decade, our authors will be looking ahead in the following areas: power reactor technology, reactor materials, reactor safety, reactor physics, nuclear fuels, chemical separations technology, nuclear chemistry, radioisotopes, nuclear physics, nuclear propulsion, fusion, nuclear instrumentation, and the outlook for utilities and nuclear equipment manufacturers.

■

Ici on parle français. Continuing on our reminiscent path, we're reminded by an article in this month's issue (p. 45) of an experience we had back in 1949. At that time, we received an article on a proton microscope from a French author written in the French language. For some reason, after having it reviewed by someone who read the language, we accepted it with our taking the responsibility of getting it translated. Our consultant did, we thought, a beautiful job of translating it. Then we sent proofs to the author. When we got his critical reactions, we vowed never again to accept papers in anything but the English language.

Then came this month's fascinating paper by Jacky Weill of the French AEC. We almost said "no" but finally yielded under the pressure of our staff, half of which reads French. And so Assistant Editor Hoby Ellis, who has a fine physics and French background (he studied for his thesis exam in Paris), tackled the paper and won the author's approval—and ours.

Hoby, by the way, is tri-lingual. He also translated from the German—with a fine assist from a feminine friend—a special contribution that we've received for our anniversary issue from Otto Hahn, Nobel prize winner and codiscoverer of fission.

●

How to report meetings. With the plethora of nuclear meetings, we're continually perplexed on how to tap, for our readers, the vast outpouring of information. Should we present summaries of papers? Should we just publish over-all highlights? Should we just solicit certain of the papers?

Ideally we'd like to do all these. Practically, we're severely limited by how many staffers we can break loose for any one meeting.

Always willing and eager to try a new approach, we've done just that this month (p. 61) in our report on the Pittsburgh American Nuclear Society meeting. As is usually the case with such meeting reports, all the material is staff written (by the team of Managing Editor Dan Cooper and Assistant Editor Hal Davis). We've combined the informality of specially taken "corridor" photos, with brief highlights of certain of the papers, with extended summaries of several particularly interesting ones. Hope you find it useful. Do you?

—The Editors

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Coming Features in NUCLEONICS

Next Month—Tenth Anniversary Issue

Later Months—Fuel Reprocessing Series

Reactor Foldout 3—
Oak Ridge Research Reactor

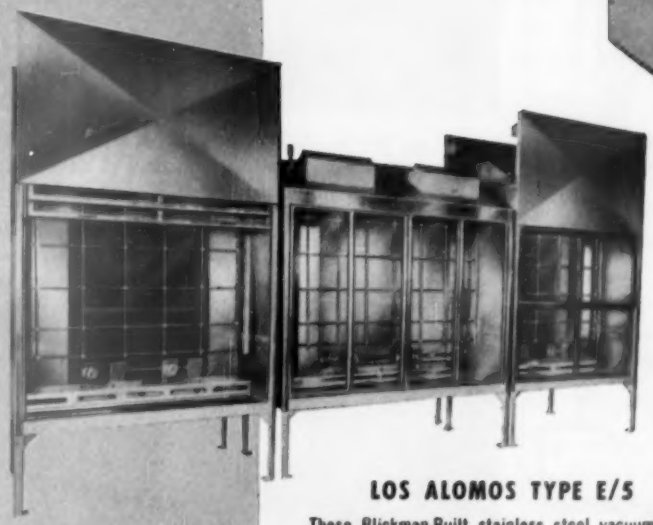
Swedish Reactors

Blickman-Built

STAINLESS STEEL

VACUUM RACK ENCLOSURES

FOR HANDLING RADIOISOTOPES AND RADIOACTIVE MATERIAL



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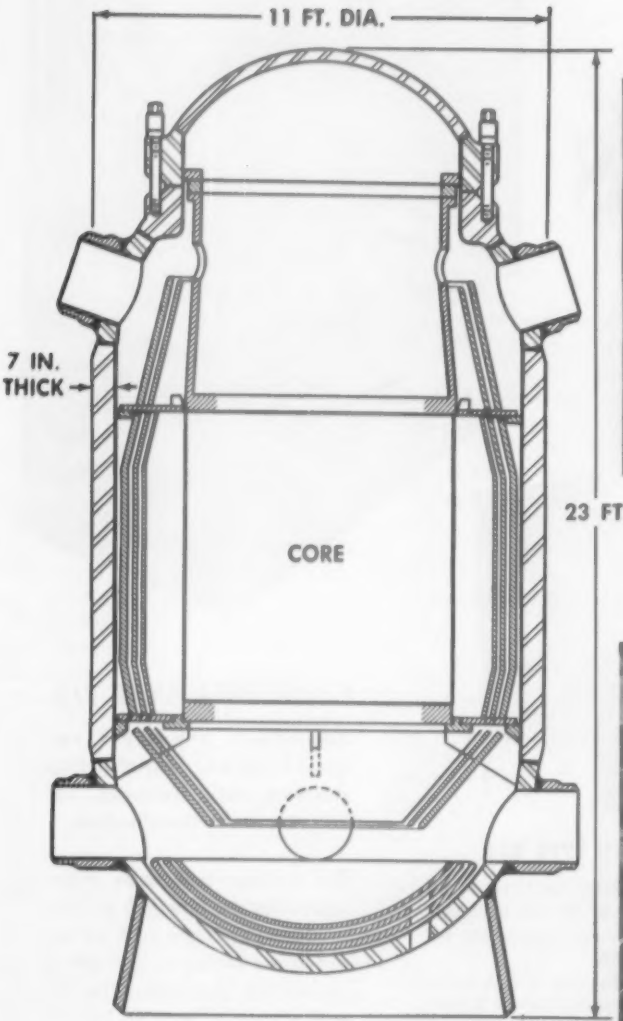
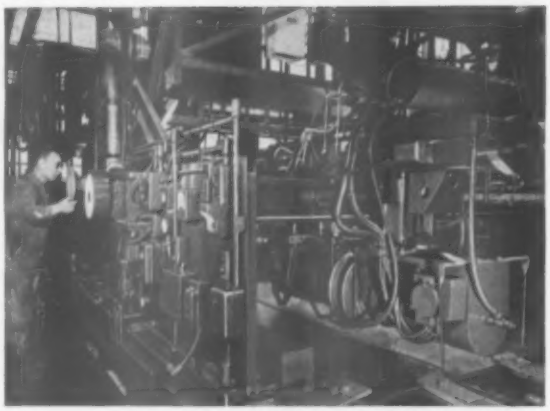


REACTOR VESSEL



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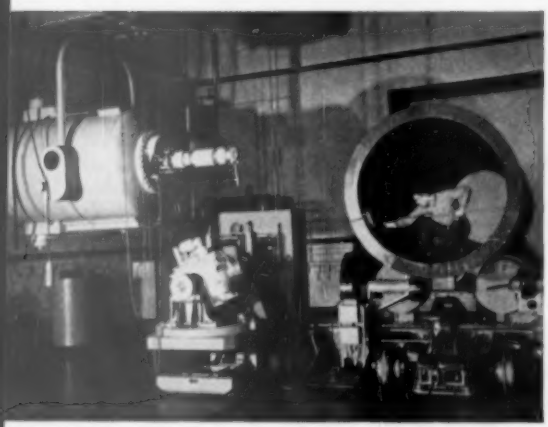

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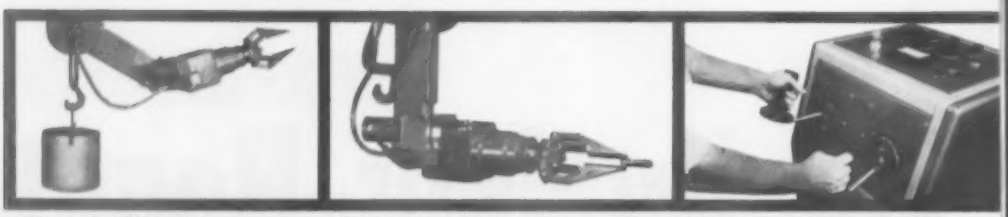

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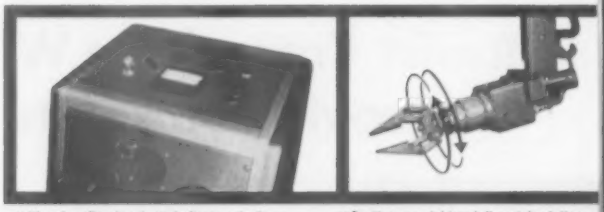
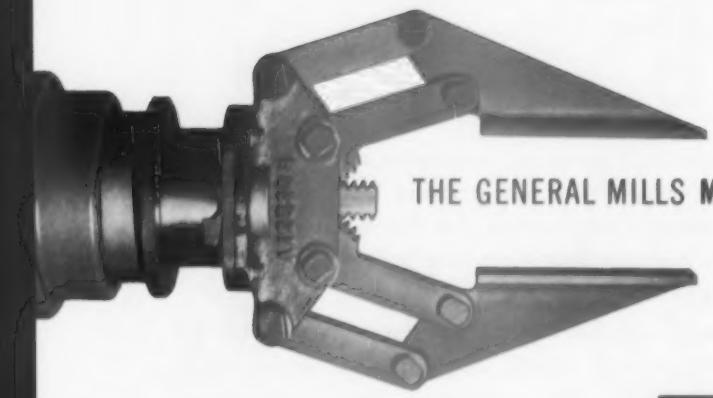


* Visual-audio signals to indicate grip force. * Continuous, right or left, wrist rotation.



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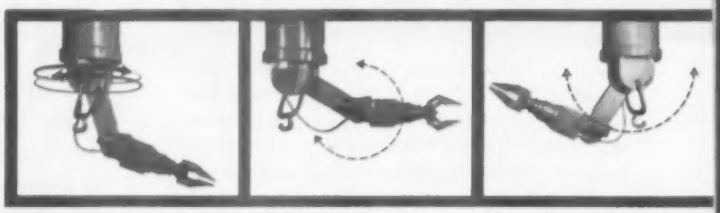

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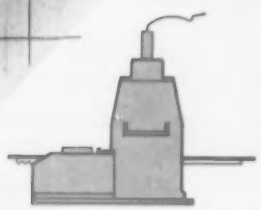

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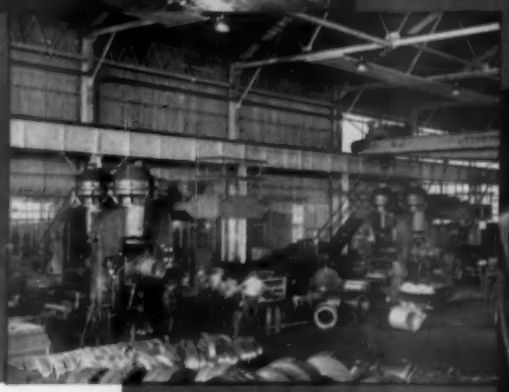

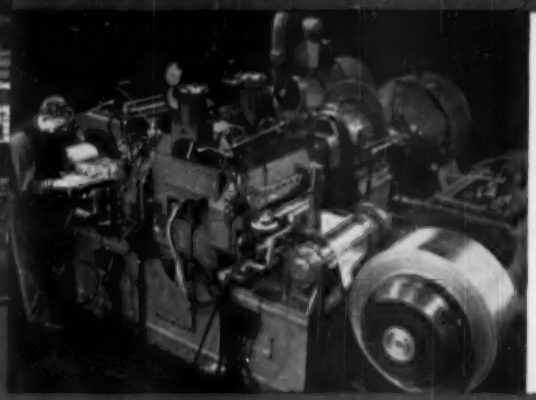

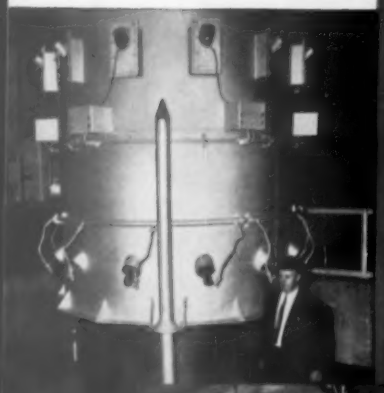

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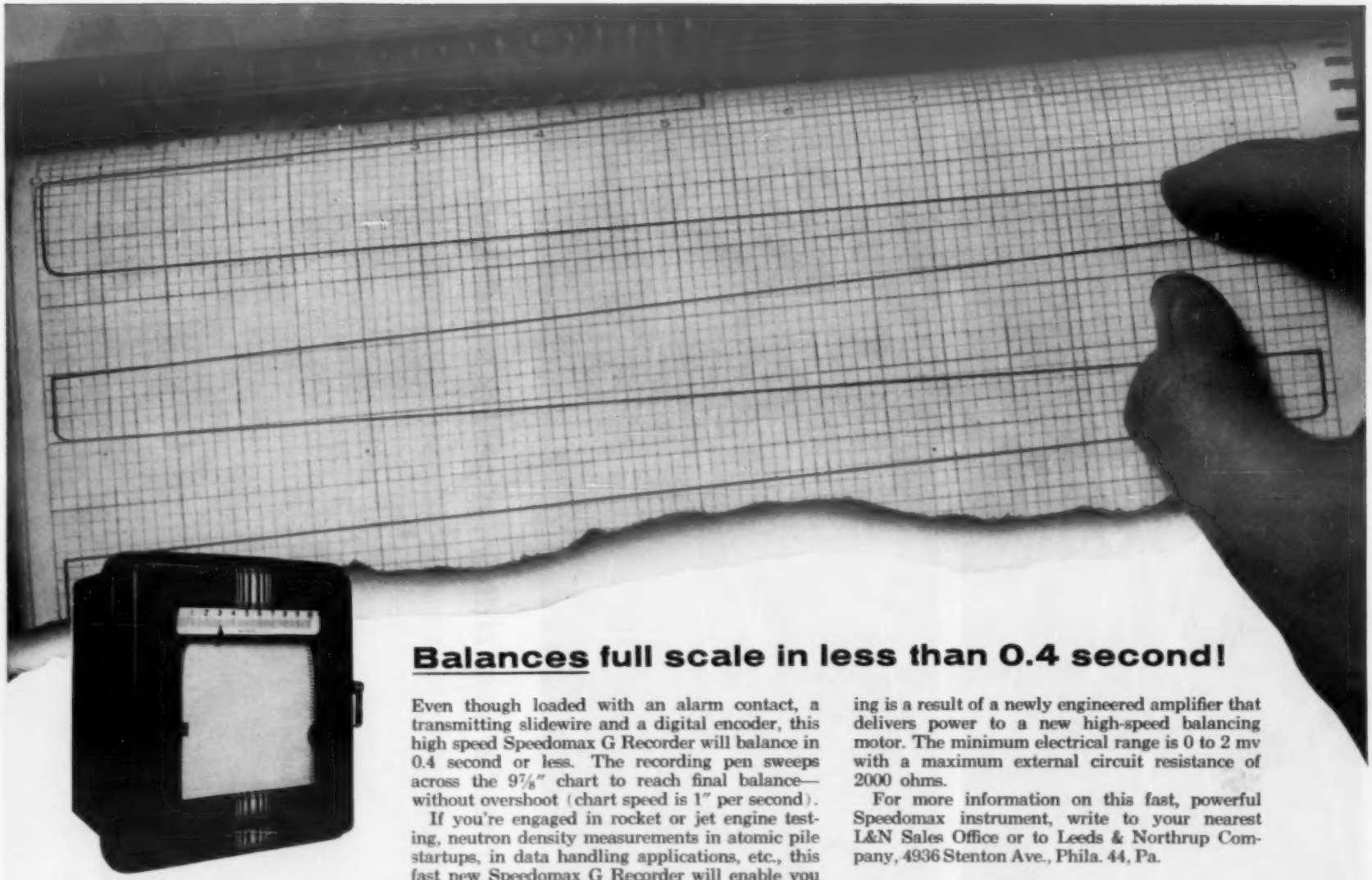

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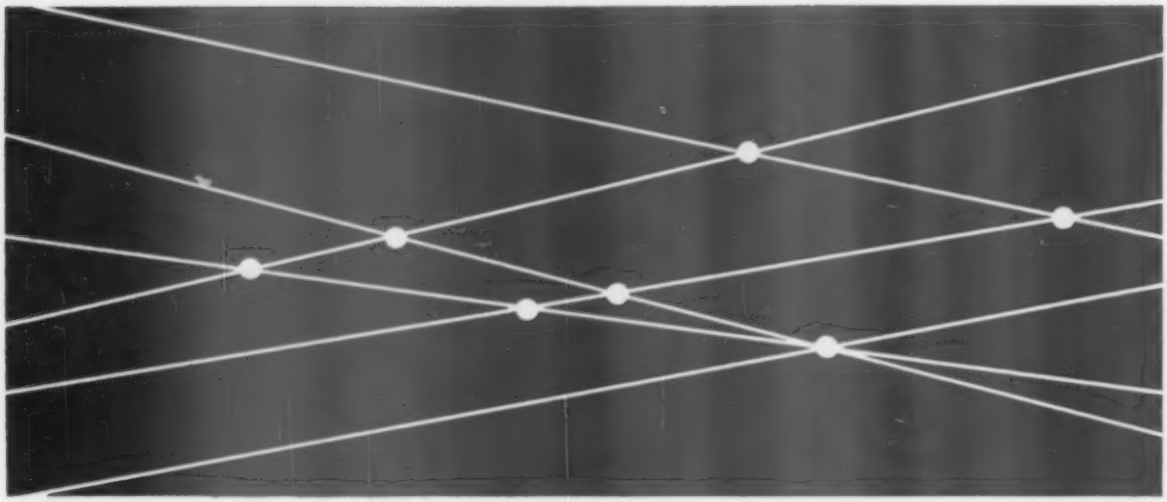

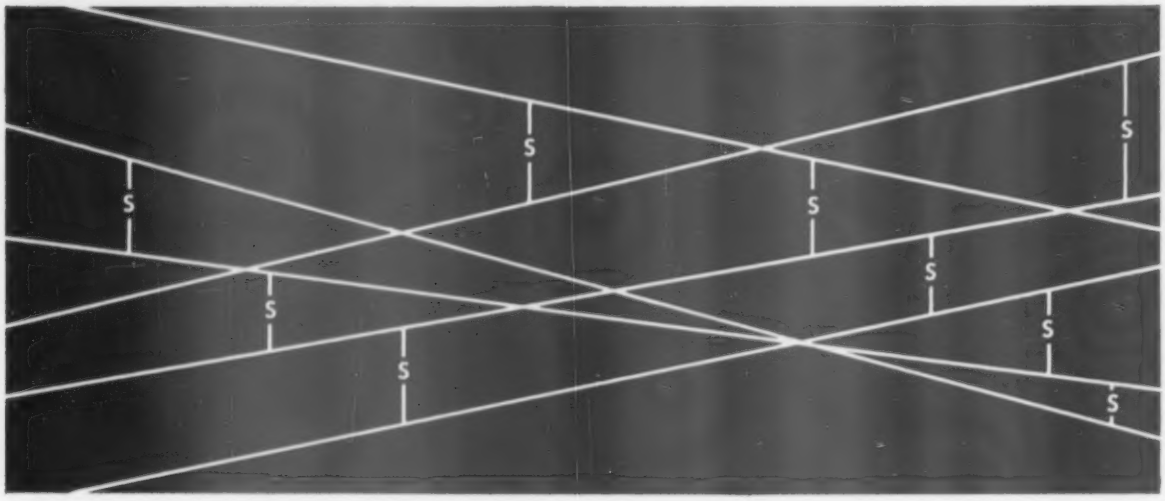

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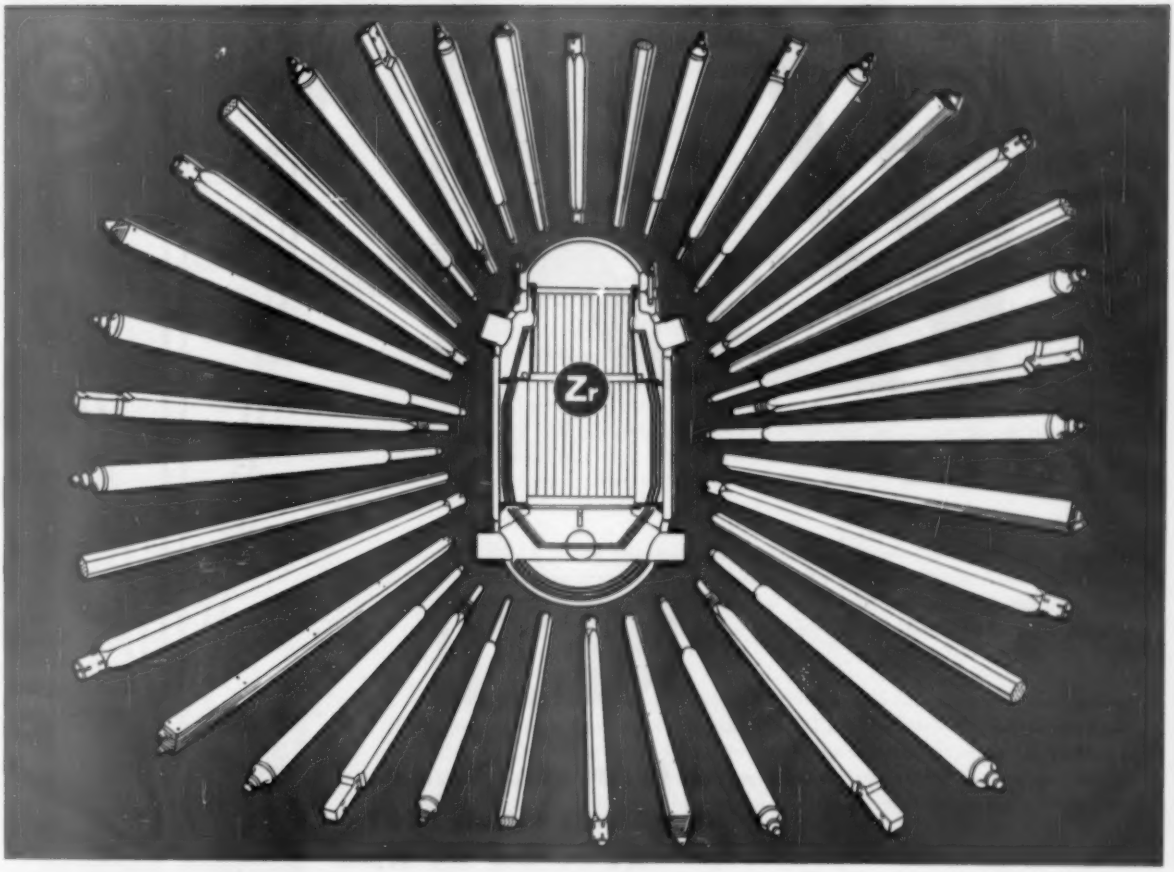

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ROUNDUP of Key Developments in Atomic Energy

Congress, AEC Hassle Over Civilian Program; Calder Type Sought

The nation's civilian reactor development program appeared to be up for grabs last month. AEC and Congress' Joint Committee on Atomic Energy were locked in a spirited tug-of-war over the civilian reactor development program, with a battle royal on the floors of both chambers forecast when JCAE's attempt at compromise comes up; the outcome was anyone's guess. Behind it all hovered the civil rights debate in the Senate with its potential for filibuster still undissipated, and thus carrying the threat of no action being taken on next year's atomic development budget authorization—or, just as bad, a slapdash authorization bill being rammed through in a last-minute scramble for adjournment.

[After this was written, JCAE voted out an authorization bill, comment on which appears at right.]

The tug-of-war developed as AEC and JCAE were busy trying to hammer out a new relationship following passage of the Durham amendment in June (NU, July '57, 19), under the terms of which JCAE and the full Congress must authorize each individual project appropriation instead of authorizing merely a blanket budget outlay. Neither AEC nor JCAE wanted this change—it was forced on both by the threat of crusty Clarence Cannon, Democratic but independent-minded chairman of the House Appropriations Committee, to block all atomic appropriations not authorized item by item. But since the change had come, both AEC and JCAE were maneuvering, understandably enough, for the solidest footing, the strongest possible position. And the Democratic majority in JCAE still—as ever since the Gore bill debate—wanted to force AEC to undertake construction of civilian power reactors; Administration forces were ready to resist to the bitter end.

Lines are Drawn

For bystanders, the confusion began Tuesday afternoon, July 9, when AEC chairman Strauss and his top aides appeared before JCAE in closed session to discuss the future of the civilian reactor program. By all accounts, the meeting was a

An Editorial

"Atoms for Peace" in Jeopardy

On July 30, the Joint Congressional Committee on Atomic Energy took action that may prove to be the turning point in the world race for preeminence in civilian nuclear power—a turning point against the best interests of the United States. For on that date the committee effectively announced to the world that, although up until that time the U. S. had the most advanced program for the development of enriched-uranium power reactors, and although the U. S. had been promoting the advantages of such systems to its foreign friends, now the Congress felt that the British natural uranium system was better and that consequently there was no need to be so liberal in dispensing U^{235}.

The JCAE made these points via two actions: one to hamstring the President on making U^{235} available to the International Atomic Energy Agency by requiring Congressional approval of such allocations, and the other by forcing the Atomic Energy Commission to build a 40-Mw Calder Hall-type reactor.

Regardless of the merits of the arguments on enriched vs natural uranium, the fact remains that AEC and American industry have built up an unsurpassed competence in enriched-reactor technology. At the moment, to be brutally realistic—and right or wrong—this is all we have to sell to other nations. And we have been selling it—successfully!

But to back up the sales efforts, it has been necessary to assure our foreign customers of a continuity of supply of U^{235}, whether through their bilaterals with the U. S. or through the International Agency, fed largely by the U. S. Now, possibly in actuality, but certainly psychologically, that assurance has been wiped out by the JCAE action.

If that were not enough, the Committee has passed judgement on a technical matter, namely that the Calder-type plant that so suits British needs should be pushed hard by the U. S. in the face of recommendations by our top reactor specialists that other types of natural uranium systems would pay more handsome dividends outside the British Isles.

Here, too, we're shouting to the nations of the world, many of which are still debating the merits of the U. S. and the U. K. systems, that the British were right and that all should "buy British"–!

In addition to these actions directly hitting at the U. S. "atoms for peace" effort, JCAE may well have stabbed in the back AEC's entire power demonstration program, which calls for joint participation by AEC and industry. It did this by voting to rescind the promise AEC made to the Power Reactor Development Co. to support it to the tune of $4–5-million. The danger here is that the entire demonstration effort to build large plants on a cooperative basis is jeopardized because companies will no longer enter into agreements with AEC if they find that Congress may lightly set aside an agreement made in good faith.

The future of the U. S. reactor program is at stake in the action that Congress takes on the recommendations of the JCAE. Those who have a firm belief in the essence of the course we have been following thus far can only hope that Congress will rebuff these recommendations.—JDL

stormy one; less clear was what had transpired. A Democratic member said Strauss had reluctantly agreed to AEC taking over the program for construction and operation of four small and one medium-sized nuclear power projects planned by rural cooperatives (Chugach, Elk River, Piqua, Wolverine and Consumers of Nebraska). Strauss issued a statement denying he had agreed to the change, declaring "my apposition to Government construction and operation of large atomic reactors for the generation of electric energy is unchanged." Whether "large" was the key word there it is impossible to say, but there seemed to be reason for surmising that the change was in fact being forced upon him willy-nilly. Chairman Carl T. Durham (D-N. C.) of JCAE seemed determined to find a compromise area acceptable to both sides. Also at issue were a number of other reactors that JCAE has been urging AEC to build, including a gas-cooled of the Calder Hall type (distinct from the high-temperature, closed-cycle Gas Cooled Reactor Experiment that Aerojet-General Nucleonics will build for AEC at the Idaho testing station (NU, Nov. '56, R6), and a plutonium recycle system, on which General Electric is doing preliminary work for AEC at Hanford.

JCAE Drafts a Formula

Then on July 23, JCAE's subcommittee on authorizing legislation approved a new version of the HR 5889, the authorization bill, and on July 30 this was voted out by the full committee. The latest version provided:

- That "arrangement for projects sponsored by cooperatives and publicly-owned agencies shall be carried on by direct contract between the Commission and the equipment manufacturer or engineering organization with respect to the development, design and construction of the reactor and related facilities; and by direct contract between the Commission and the cooperative or publicly-owned organization with respect to the provision of site and conventional turbogenerating facilities, operation of the entire plant including training of personnel, the sale by the Commission of steam from the reactor complex to the cooperative or publicly-owned organization, and other relevant matters." This is the AEC–Duquesne Light Co. formula for Shippingport, where AEC contracts directly with a manufacturer for construction and with a utility for operation; it substitutes for what had until now been the Power Demonstration Reactor Program formula where AEC's prime contract is with a utility, and the utility subcontracts with a manufacturer for construction. This has been the crux of the argument between AEC and JCAE: it has not been a question of which way is the cost to the Government less, for in either case AEC would bear the brunt of the expense, but rather one of how much does the small cooperative utility have to contribute to the program—should it be made the prime contractor? The bill further provides that "sale of steam by the Commission under contract with the cooperative or publicly-owned organization shall be at rates based upon the present cost of, or the projected cost of, comparable steam from a plant using conventional fuels at such locations."
- AEC "shall proceed with the design, engineering and construction under contract as soon as practicable" of two prototype power reactors: a natural-uranium, graphite-moderated, gas-cooled power reactor prototype for about 40 Mw, to be built at the Idaho testing station for $40-million; and a plutonium recycle experimental reactor of 15 Mw to be built at Hanford for $15-million. The electricity from these plants is to be used by AEC at the installations named. In addition, there is authorized expenditure of $3-million for preliminary work on a dual-purpose reactor primarily for production of weapons plutonium.
- $1.5-million is authorized "for additional general research and development to advance the technology of the fast breeder reactor concept" —a Congressional slap at the Power Reactor Development Co.'s Fermi fast breeder project at Lagoona Beach near Detroit, for which AEC had asked $4.2-million research and development aid.

JCAE Brief for Gas

As for JCAE's espousal of the Calder Hall type, there were those observers who feared that this might be interpreted abroad as a U. S. admission that the British have been right all along. JCAE's feeling is that the gas-cooled graphite-moderated reactor represents an obvious gap in our program; that we very properly have a broad program, and should continue to cover all good bets—that we cannot afford not to try out and learn about a type that has been so successful in Britain; that our own two most successful reactor designers, Walter H. Zinn and Rear Adm. H. G. Rickover, both recommended building one.

Red A-Ship

The Russian nuclear - propelled ice - breaker 'Lenin' shown on the stocks at a shipyard in Leningrad. 16,000-ton vessel will have turbo-electric drive; 44,-000-hp electric motors will give her 18-knot speed (NU, June '56, 18B; Aug., R3; Feb. '57, R11)

Other Authorizations

Authorized items also include:

- $5-million for a fuel element manufacturing plant where a cost saving from 25 to 50 ¢/lb of finished slugs is anticipated by using extrusion as against production by the present method of rolling.
- $9-million for test installations required for study of nuclear power application to missile propulsion.
- $10-million for a fuels technology center at Argonne (NU, May '57, 22).
- $3-million for a high-temperature test installation at Bettis for performance of core experiment.
- Deleted was $9-million for a power reactor for the Puerto Rico Water Resources Authority (NU, May '57, 23).

Hearing Comments

At hearings earlier before JCAE on the projects up for authorization, the following significant comments were made:

On budget cuts—Kenneth E. Fields, AEC general manager: AEC had removed from its budget two contingency items for an aqueous homogeneous and a natural-uranium heavy-water power reactor "if industry did not pick up" these two types in the third-round of the Power Demonstration Reactor Program. The former was to have been a 100–150-Mw, $50-million converter using highly-enriched uranyl sulfate; the latter was to have been of the same output and cost. Other items dropped—these eliminated by the Bureau of the Budget—included $17.5-million for a fuel element test reactor, $2-million for a critical mass laboratory, and $5.5-million for an irradiation test reactor at Argonne.

On fusion power—Fields and T. H. Johnson, AEC director of research: Funds asked for Project Sherwood were increased from $5-million to $7.75-million, as consequence of "a considerable amount of progress in reaching higher temperatures" and "better understanding of some of the instabilities . . . both from having been proven experimentally and from better understanding of theory." Of the higher figure, $5.6-million is for buildings to house the Model C Stellarator at Princeton (NU, May '57, 108), which will cost $17.5-million for a "huge generator, power condensers, electronic gear, vacuum equipment."

Nuclear merchant ship progress reported

Shipbuilders and ship operators 250 strong got the word on nuclear merchant ship progress at a symposium held by the joint AEC-Maritime Administration development group. They heard the first detailed description of the first nuclear merchant ship, for which a shipyard is to be chosen this fall; keel-laying is due in spring and launching a year later. The Babcock & Wilcox pressurized water reactor will be shielded by 33 in. water in an annular tank and 3 in. lead, and with the two primary loops will be enclosed in a 50-ft long, 35-ft dia containment vessel amidships. Fuel will be low-enrichment oxide rods. The 588-ft vessel will have 30 cabins for about 100 passengers. Also presented at the symposium were interim reports on study projects for advanced liquid and gas-cooled reactor systems. Esso President Gamble said Esso Shipping Co. "would like to be the first to own and operate an atomic tanker."

131,560 pounds of U-235

The U. S. government, in its third annual determination of the state of the national U^{235} stockpile, has freed an additional 59,800 kg (131,560 lb) for peaceful uses—30,000 kg for domestic needs, 29,800 kg for sale or lease abroad to individual nations or groups of nations. In addition to 40,000 kg made available last year (NU, March '56, 17; April '56, 19) and 200 earlier, the new allocation brings the total to an even 100,000 kg—220,000 lb, valued at $1.7-billion at current prices. This is estimated to be sufficient to yield (over a period of years) 3,000 Mw electricity—less than the U. S. projection of nuclear capacity over the next five years, but only one-fifth of Euratom's 1967 goal. AEC chairman Lewis L. Strauss said existing allocations under licenses to domestic reactor builders now approximate 17,000 kg—close to the 20,000 kg limit before the new determination raised it to 50,000. Foreign countries' plans to use U. S. enriched uranium under power bilaterals "indicate that their needs also will exceed the 20,000 kg of U^{235} previously made available," Strauss added; total available for export now is 50,000 kg.

Westinghouse licenses Belgian, Italian firms

Westinghouse has completed technical assistance agreements covering production of complete nuclear reactors and related apparatus with two major European industrial firms—Ateliers de Constructions Electriques de Charleroi, Belgium's biggest electrical manufacturer, and Italy's vast Fiat works. By coincidence, the first and second license agreements were concluded in the same countries that were first and second to purchase Westinghouse power reactors. ACEC and Fiat will be able to manufacture pressurized water, aqueous homogeneous and other non-military reactors developed by Westinghouse using the latter's technical know-how. ACEC hopes to become a supplier to Euratom; the first Euratom order is scheduled to be placed late next year. Provisions exist in the contract for other companies in Belgium's Société Générale group such as Cockerill-Ougrée and the Société Métallurgique de Hoboken to come in under the agreement. On the other hand, Fiat, although a member with Montecatini of the Sorin group, is acting alone. Fiat is also interested in building a materials testing reactor of the WTR type. Westinghouse is also negotiating a license agreement with Mitsubishi in Japan (NU, April '57, 17; Aug., 27) and a firm in West Germany.

Plutonium Price Impact Studied by Industry

The impact of AEC's new plutonium prices (NU, June '57, 17) is still giving nuclear economists sleepless nights.

Up to last November, the only clue to the value of plutonium lay in a classified price scale, now known to have ranged from $12 to over $45/gm depending on characteristics of the metal. In November AEC announced a "guaranteed fair price" of $12/gm for Pu buyback for the one-year period from mid-1962 to mid-1963 (NU, Dec. '56, R1). Two months ago AEC abruptly announced a new scale of prices superseding the one in effect: from Feb. 1, 1957 to June 30, 1962, Pu was to be pegged at from $30 to $45/gm depending on Pu^{240} content, according to the table below; for the year following, the price was raised from $12 to a flat $30/gm.

% Pu^{240}	Price, $/gm Pu
0.0	45.00
2.0	41.50
4.0	38.00
6.0	34.50
8.0	31.00
8.6 and over	30.00

Reason for the variation in the pre-'62 price is that Pu^{240} content is undesirable in plutonium intended for weapons use. The Pu is to be delivered to AEC's Rocky Flats plant outside Denver in the form of buttons from 200 to 2,000 gm each and 99.5% pure.

The action focused attention on the double standard existing in the plutonium market—a $45 premium price for weapons-use Pu, and a lower value established at $12/gm—now raised to $30 for one year 1962–63. Also, uncertainty was engendered by AEC's policy statement accompanying the new prices: "It is emphasized that, while the Commission intends to extend the guarantee period for plutonium prices each year for one additional year, the prices which will be established for subsequent years may be different from those previously in effect. In particular, it is the expectation of the Commission that the prices for plutonium will be reduced, as dictated by consideration of the value of the material for its intended use by the U. S. and giving such weight to the actual cost of producing the material as the Commission finds to be equitable, to a level based upon the fuel value of plutonium in commercial power reactor facilities." The last clause is being interpreted as meaning that AEC's intention is to bring the fuel price ultimately back down to $12/gm.

It was the interplay of these two factors—the double market and the hint of eventual lower fuel prices—that made it so difficult to gage the impact of the move on industry. As one of the keenest observers, Walter H. Zinn, put it before Congress:

"When AEC announced its increase in price from $12 to $30, I'm afraid what it did was to confuse everyone in the civilian power field, because it was realized right away that very few reactors would produce much plutonium before 1963, and we know that period was limited by the seven years [maximum that AEC may guarantee prices, under the 1954 Act].

"So the supposition is that the high price—the $30—will extend for some time beyond 1963. If that is true, those people who are planning thorium reactors are taking a terrific disadvantage. They are losing considerable money by not having uranium in their reactors and selling plutonium to the Government. So it has confused the issue rather considerably, and it would be very helpful if one had any idea that this $30 price would go on for some years after 1963. If it did, I would hazard a guess that those people who are planning to use enriched uranium and thorium would really find themselves switching to uranium, because it makes a big money difference to them.

"As far as I can figure out, the enriched uranium–thorium fuel cycle is just as good, every bit, as the slightly enriched uranium cycle, at the $12 price for plutonium and the $15 price for U^{235}. But when you jack the price of plutonium up to $30, then there is not really a comparison any more. And right now, you just do not know what to do, because there will not be very much plutonium produced in the civilian program by 1963. . .

"It is a matter of guessing, now. People say, 'Should we guess that plutonium prices stay up for another four or five years?' Well, I do not know how to advise them."

Effect on Operators

The only thing certain was that—so far as they went, up to mid-1963—the new prices would have different effects on different companies. For Yankee Atomic Electric, it was a windfall; for Power Reactor Demonstration Co., the Detroit fast breeder group, it was a catastrophe. Yankee's Pu production starting in 1961 will be a bonus, while PRDC's contract with Detroit Edison provides for only one-third to one-half of total reactor cost to be met from sale of steam—the rest was to have come from AEC buyback of Pu.

Observers sympathetic with PRDC's plight contend that even at $45/gm for Detroit Pu, AEC would be getting a bargain—since a fast reactor makes higher-grade Pu (in terms of low Pu^{240} content) than a thermal unit, and since $45/gm is believed to be the Commission's own average (not marginal) cost for Pu from its thermal production reactors at Hanford and Savannah River. They suggest also that perhaps there should be not two but three prices for Pu, to reflect existing conditions realistically: a premium weapons price, a fuel price, and an intermediate experimental price for a limited amount of Pu used in its development as a fuel. Also criticized was the fact that not even on a classified basis could industry learn how the prices were arrived at, let alone be consulted during the rate-making process.

Industry voices taking a contrary viewpoint said it is very well for private industry to advance the art, but that it is a misjudgment to take a policy position in the power business that half one's income comes from sale of Pu—that if one goes in on the basis Pu is worth x, and it turns out to be worth ½x, that's the risk one takes.

Most industry people consulted were agreed that it is pity to mix up reactor development with a premium price for weapons-grade Pu, but that the present situation would undoubtedly influence reactor design. It was generally felt that it would have been better to separate reactor development and plutonium procurement completely by putting a flat termination date on the $30 price, and establishing a long-term fuel price of a flat $12, if that is what the real fuel value is. The British, it can be computed from an analysis of their published data, value Pu at $14/gm.

AEC is now between devil and deep blue sea: it fears giving a clue to post-'63 plans lest it be construed as an illegal guarantee, so cannot end industry's perplexity.

Davis Sees Soviets' Power Program Slowing

Agreeing with a NUCLEONICS estimate (NU, July '57, 20), AEC reactor development director W. Kenneth Davis told the Midwest Council of State Governments that AEC had recently "received confirmation that our doubts of a year ago were quite justified [doubts that the Russians' 2–2.5-million kw nuclear power goal by 1960 would be accomplished]. This is in an official USSR reply to a U. N. questionnaire and in a series of papers presented at the Belgrade meeting of the World Power Conference. While it would be a mistake to discount the ability of the Russians too far, it is clearly apparent from the information now available that the USSR program is actually of about the magnitude and character which would seem to be reasonable as compared with the highly exaggerated claims that were made last year. One interesting feature of the USSR program is that it looks more and more like the U. S. program. It now appears that the Russians are lagging in technology and may hope to obtain guidance through U. S. advances which, of course, are available throughout the world. . . .

"The proposed Russian pressurized water reactor is very interesting. Its design is remarkably similar to that of our Shippingport PWR in every respect. The Russians are, however, planning for a turbogenerator capacity of 210 electrical Mw per reactors as compared with 100 Mw for our reactor. This is being done with three 70,000 kw turbogenerators, however, which may indicate the Russians only plan to install all three if the reactor can, in fact, be operated at that high a power level. . . .

"There seems to be good reason to believe that these changes arose because in 1956 the Russians had not gotten far enough into their program to even realize what the difficulties in development and manufacture really would be. In other words they were naive about their proposed program. It seems likely that during the past year the Russians have come face to face with the real difficulties of their announced program and have had to revise its size downward. . . . Their program can be much more independent of honest economics than our own—and that these have still been their decisions."

Declassification Here in Act, Slow Coming in Fact

Declassification of the civilian reactor program is largely completed, but still far from it in practice. This appears to be the situation today, as assayed by an informal NUCLEONICS spot-check survey.

By the terms of a new tripartite (U. S., U. K., Canada) declassification guide concluded at the end of last year (NU, Jan. '57, R2), a review of 18,677 classified papers was carried out by an AEC Committee of Senior Reviewers; 9,076 or 48.6% were declassified. Of the remainder, 5,294 were left in the "confidential," or gray area, and 4,307 were guarded as "secret." AEC contended that with this action, virtually all civilian reactor technology —all, in fact, that did not have a bearing on military or production reactors—was declassified and freed for public use without trammels. Some demurrals by industry people led NUCLEONICS to make a check.

Of the prominent reactor designers consulted, all but one said that everything is not declassified. One cited unavailability of depleted uranium price figures, which prevents figuring all the way around a fuel cost cycle. Others said some of the Shippingport PWR papers were still unavailable; that basic work done some time ago on metal-water reactions is still confidential; that the properties of uranium dioxide are still mostly classified; that "little of really useful data from the submarine program gets declassified"; that economic information is still sticky to get. Said one: "It's far from all out in the open—that I can make as a positive statement. About 10% of the pressurized water technology papers of interest to us are still classified, or else our library has received no notice that they have been declassified."

That last remark appears to hold the key to the situation.

AEC's Answer

For when confronted with these industry plaints, AEC's director of classification, Charles L. Marshall, declared flatly that all Shippingport data has been completely declassified, barring nothing; that 47 other AEC reactor and critical experiments and 38 private reactor projects are likewise completely declassified; that uranium dioxide technology has been declassified; but that the culprit in the situation is the time lag in making required deletions, printing and distributing.

As of the beginning of July, he said, "more than 3,000" of the newly-declassified documents have been made available on public sale or through AEC's Technical Information Service. This of course is only one-third of the number of papers declassified in June. It is hoped to get "substantially all useful documents" of the remaining 6,000 out by mid-September.

"So people may be asking for documents and getting the wrong answers," says Marshall, "just because of the time involved." A classified document in a company library safe may have been declassified by act of AEC, but unless the company librarian has received the notice of declassification, and stamped the document "declassified," company engineers will still be balked in getting the paper. It would appear, therefore, that the monumental mechanical job of implementing declassification remains the major obstacle, rather than a narrow secrecy policy. But it will not be until this mechanical job has been completed, and the papers' contents diffused among private reactor designers, that it will be possible to determine whether civilian reactor technology has really been completely declassified or whether there still remain blank areas.

Presumably, by the time of the 1958 Geneva atomic energy conference, any classification that's in effect will be trade secrecy rather than military secrecy, the reverse of the situation at Geneva in 1955.

AEC Licensing News

Notice of proposed issuance of operating license: General Dynamics, for an experimental nuclear facility and a series of initial uranium foil experiments, at San Diego, 7/25/57

Notice of proposed issuance of construction permit: Atomics International, to build a 5-watt enriched uranyl sulphate solution research reactor, at Canoga Park, Calif., 7/17/57

Applications received: General Electric, to build a 3-kw, light-water moderated test reactor at Vallecitos, Calif., 7/1/57

AMF Atomics, to export a 1-Mw, pool-type research reactor, to Società Ricerche Impianti Nucleari (SORIN), Milano, Italy, 7/3/57

2½-Million Kw Installed in Naval Ships by 1963—Rickover; He May Develop Gas-Cooled Unit; Sees Industry Willing

"Projecting the present rate of nuclear shipbuilding, we would have by 1963 about 1½-million kw of power in operation and an additional million kw in ships under construction," Rear Adm. H. G. Rickover, chief of AEC's naval reactors branch, told the Joint Committee on Atomic Energy in a closed meeting, transcript of which was published last month.

The record also disclosed that two prominent JCAE members—research and development subcommittee chairman Rep. Melvin Price (D-Ill.) and military applications subcommittee chairman Sen. Henry Jackson (D-Wash.)—recommended that AEC "consider immediate assignment to the naval reactors branch of the development and construction of a new civilian reactor concept. With the prospective completion of the pressurized water reactor at Shippingport, additional time and attention could be given to a new reactor type. We specifically call attention to the desirability of assigning the development of an advanced-type gas cooled reactor, and point out that some years from now the knowledge acquired in the development of a gas system may have application for ship propulsion."

Rickover was asked during the meeting, "If you had the privilege of naming the type of reactor that you would like to go into, which would you select?"

RICKOVER: Gas cooled.

Rep. HOLIFIELD: Gas rather than the homogeneous?

RICKOVER: Yes, sir.

The Admiral also revealed that he expects to ask funds for a prototype destroyer reactor in fiscal 1959—indicating that work on this most difficult reactor size is apparently progressing well (NU, July '57, 69). Rickover said the prototype would be installed in the West Milton sphere that had been built for the *Seawolf* prototype (NU, April '57, 24).

The Core Business

Rickover discussed the procurement of naval reactor cores and other components and the development of a supplying industry:

"The next important thing we had to do [after assuring zirconium supply] was to get more facilities for making reactor cores. Our practice right now is to have our laboratories develop and make the first core of a type, and thereafter to put it out on competitive bidding.

"For example, take the core for the 578-class submarine [the four *Skate*-class subs]. About eight months ago we asked for competitive bids for five of these cores. We now have a number of companies that have equipped themselves at their own expense to manufacture cores on a competitive basis: Westinghouse Electric Corp.; Olin-Mathieson Co. at New Haven, Conn.; Metals & Controls Corp. at Attleboro, Mass.; Combustion Engineering Co. at Windsor, Conn.; and Babcock & Wilcox Co. at Lynchburg, Va. Each company has put in at least $3-million of their own money, again with no certificate of necessity, for the necessary facilities. They have taken contracts for these cores on a competitive basis. On this basis we were able to order these cores for less cost.

"We have just put out proposals for seven cores for another type of submarine. *[This would be the S5W type.—Ed.]* These will all follow the design of the first one, which is a developmental job, and which was designed and built at the Bettis Laboratory. All will be made in commercial facilities and competitively. We are getting industry to make as many other components as possible for our nuclear plants. So that even as we are going along with the design of different types of plants we are establishing the industry necessary to carry the production along.

"Insofar as components for nuclear powerplants for these ships are concerned—I looked this up just the other day—we have placed orders for $29-million for nuclear parts competitively: this is about 86% of what we are buying now on competitive lump-sum bidding, and only 14% is bought on cost-plus basis. This consists of items such as controls where the development is still in progress and sources of supply have not yet been developed. I am not talking about the steam machinery; that is all bought competitively. . . ."

HOLIFIELD: Do you have any trouble getting private companies to bid on these different components?

RICKOVER: Not on reactor cores. We have difficulty with things like valves because they, as well as many other items, are very special. They have to be made leak-tight, and they require a great deal of engineering. As long as we have an economy where people can get lots of business by doing conventional stuff, not too many want to get into this special field. More companies would rather use their engineering staffs on conventional items because they can make more money that way. But those who look to the future know that this is good business to learn the new techniques which are going to be necessary if they are to remain competitive tomorrow. It is these forward-looking ones who are getting into our business. We have really had to fight with people to take our orders.

Rep. PATTERSON: Who pays for tooling on special valves?

RICKOVER: They do. We are trying to get this program into industry as fast as possible—to buy it like a loaf of bread.

PATTERSON: You could not expect any manufacturer to put a special gear into a plant where he is going to make only 200 or 300 or probably even two.

RICKOVER: Yes, sir; I do.

PATTERSON: You expect him to do that?

RICKOVER: Yes, sir.

PATTERSON: And have them pay for the tooling?

RICKOVER: Yes, sir. Sure. Why not?

Rep. PRICE: Are they doing it extensively?

RICKOVER: Yes, they are.

HOLIFIELD: Do they do it at a loss to themselves?

RICKOVER: Look, next year we are going to have about $50-million worth of reactor core business alone. It is like a fuel business. Once you get a ship in the water with a core you have got it there three or four years, then you have to take the core out and put a new one in. It is like the oil business.

Zirconium Supply

As regards the supply of zirconium for naval reactors and the Shippingport PWR, Rickover said the Government will be getting about two million pounds Zr a year from the four companies with which it has contracts (NU, May '56, 21). Prices for each firm are as follows: National Distillers, $4.53/lb; NRC Metals, $6.50; Carborundum Metals (Akron, Ohio), $11.42; Carborundum Metals (Parkersburg, W. Va.), $7.72; Wah Chang (U. S.-owned facility, Albany, Ore.), $9.07.

Second Geneva Conference Schedule, Sept. 1–13, 1958

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
Morning, Sept. 1	**Morning, Sept. 2**	**Morning, Sept. 3**	**Morning, Sept. 4**	**Morning, Sept. 5**	**Morning, Sept. 6**
A. Opening of conference	C. Experience with nuclear power plants	E-1. The use of nuclear energy for purposes other than generation of electricity E-2. Progress in the use of isotopes	G. Possibility of development of controlled fusion reactors	1-2 Reactor technology 2-2 Problems in nuclear fusion 3-2 Technological application of high intensity ionising radiation 4-2 Raw materials supplies	1-4 Basic applications of chemistry in atomic energy 2-4 Physics of elementary particles 3-4 New uses of isotopes in medicine 4-4 Ore-dressing, extraction and refining of U and Th
Afternoon, Sept. 1	**Afternoon, Sept. 2**	**Afternoon, Sept. 3**	**Afternoon, Sept. 4**	**Afternoon, Sept. 5**	**Afternoon, Sept. 6**
B. The future of nuclear power	D. Plans for construction of nuclear power plants	F-1. Operational experience in health and safety F-2. Recent developments in fundamental physics	1-1 Reactor technology 2-1 Problems in nuclear fusion 3-1 Dosimetry and standards 4-1 Raw materials supplies	1-3 Basic applications of chemistry in atomic energy 2-3 Problems in nuclear fusion 3-3 Technological applications of high intensity radiation 4-3 Raw materials supplies	1-5 Properties of reactor materials 2-5 Physics of fission 3-5 New uses of isotopes in medicine 4-5 Ore-dressing, extraction and refining of uranium and thorium
Morning, Sept. 8	**Morning, Sept. 9**	**Morning, Sept. 10**	**Morning, Sept. 11**	**Morning, Sept. 12**	**Morning, Sept. 13**
1-6 Properties of reactor materials 2-6 Nuclear data 3-6 Use of isotopes in biology and physiology 4-6 Methods of separation of isotopes	1-8 Processing of irradiated fuel elements 2-8 Reactor theory and calculations 3-8 Use of isotopes in agriculture 4-8 Methods of separation of isotopes	1-10 Treatment of radioactive wastes 2-10 Fuel cycles & economics of nuclear power 3-10 Biological effects of radiation 4-10 Fabrication of fuel elements	1-12 Handling of highly active materials 2-12 Prototype power reactors 3-12 Experience in radiological protection 4-12 Processing of other materials useful in atomic energy	Y. (a) Development of international collaboration in the fields of atomic energy in the last few years	Z. Closing of conference
Afternoon, Sept. 8	**Afternoon, Sept. 9**	**Afternoon, Sept. 10**	**Afternoon, Sept. 11**	**Afternoon, Sept. 12**	
1-7 Properties of reactor materials 2-7 Nuclear data 3-7 Use of isotopes in research, control and industrial technology 4-7 Methods of separation of isotopes	1-9 Processing of irradiated fuel elements 2-9 Reactor theory and calculations 3-9 Radioactive and stable isotopes production and distribution 4-9 Fuel element fabrication	1-11 Treatment of radioactive wastes 2-11 Fuel cycles & economics of nuclear power 3-11 Biological effects of radiation 4-11 Processing of other materials useful in atomic energy	1-13 Experience in radioactivity problems arising from the operation of reactors and chemical plants 2-13 Use of research and test reactors 3-13 Experience in radiological protection	(b) Supply and training of personnel	———

N.B. General or plenary sessions are designated by letters; technical sessions are in four series, and are designated by two numbers of which the first is the series number and the second the session number.

2-14 Use of research and test reactors
3-14 Reactor safety and location
2-15 Reactor experiments
3-15 Oceanographic meteorological aspects of the large scale use of atomic energy
2-16 Reactor experiments

} These sessions will be dovetailed into closing days of conference in a manner depending on number and nature of papers submitted.

Report from France:

Marcoule's 'Steel Cathedrals' Near Completion; Pu Extraction Plant to Operate at Year's End

MARCOULE

Construction work here on France's first plutonium-producing center, located 400 mi SE of Paris amidst sun-drenched *rosé*-wine vineyards, is progressing satisfactorily. This is the report of NUCLEONICS' Paris correspondent who toured the center when it was first opened to the press last month. The center, operated by the French AEC, will consist when completed of three reactors fueled by natural uranium which together will produce some 100 kg of Pu annually, in addition to feeding about 60 Mw net into the French power network.

The first pile, G1, is already in operation, having gone critical in January, 1956. As previously reported (NU, April '56, 22), G1 is fueled by 100 tons of natural U, moderated by graphite and cooled by atmospheric air.

Last fall the French had some difficulty with G1, and it was shut down for two months. It seems the radial cooling fins on one magnesium can overheated and expanded, thus blocking the coolant air flow. The French, terming the incident a "classic" one, admit they are not quite sure what caused the overheating. The detection system on G1, they say, works quite well—that if it has any fault, it is one of "super delicacy." It is understood the detection system on the two other reactors—G2 and G3—will be simpler in nature.

Stretchout on G2, G3

Start-up dates for G2 and G3 have been stretched out somewhat. G2 is now expected to go critical in April, 1958, with G3 following six months later. The $15-million-plus Pu extraction plant at Marcoule, now in an advanced state of construction, will be in operation toward the end of this year, according to plans.

G2 and G3, being built side-by-side, are identical in all their characteristics. Each, however, will have its own control center and power plant. Steel housing rising nearly 200 ft is in place for both reactors, already dubbed the "steel cathedrals of France" by French newspapers. (Indeed, their overall dimensions actually do just about equal those of the nave in the Cathedral of Notre-Dame at Paris.)

Unlike G1, G2 and G3 will be cooled by carbon dioxide at 15 atm in a closed circuit. Each will be fueled by about 120 tons of natural U moderated by graphite. Active core of each reactor measures 27 ft 9 in. in length by 24 ft 7 in. dia. The core encloses 1,200 graphite channels, 2.7 in. dia spaced at intervals of 8 in. Fuel is inserted in 1 in. dia slugs 12 in. long, or about three times smaller than the slugs used in G1. These natural U slugs are sheathed in magnesium alloy approximately 0.06 in. thick with radial cooling fins.

Unlike G1, the loading and discharging of the 33,600 slugs in G2 and G3 will be achieved without necessity of shutting down the reactor. The French AEC has worked out a system of hermetic pressurized removal which makes it possible to eject the enriched slugs by pushing in new ones from the rear of the reactor. Slugs ejected in this manner fall into sheet metal runways at a 45° angle; gravity leads them out via evacuation tubes. These tubes, on a 50° incline, describe an arc of a circle which has the effect of breaking the fall of the ejected slugs by centrifugal force. Evacuation tubes leave the pressure vessel through 100-mm apertures and enter switch raceways joined in turn to helical toboggans, which describe spirals of 6.5 ft dia and thus complete the braking of the ejected slugs. The toboggans, themselves enclosed in concrete shells 5 ft thick, end in lock chambers closed by two hermetic shut-off gates. The slugs finally come to rest in sealed tubes which are then transported by truck to the nearby Pu extraction factory.

Work on the horizontal pressure vessel for G2 is nearing completion. The French AEC decided to combine the radiation shield and structural strength in a single enclosure of prestressed concrete 9 ft thick, 46 ft long and 46 ft o.d. Instead of bulky armor plating, the concrete pressure vessel is being lined with steel plate having a thickness of 1.2 in. The cylinder is prestressed to take an internal pressure of 427 psi.

New Program Okayed

While Marcoule nears completion, back in Paris the National Assembly finally has approved the new French five-year atomic plan for the years 1957–61. The program earmarks 384 billion francs ($1.1-billion) for various AEC projects as well as projects to be carried out by AEC for other ministries—e.g. a propulsion project for the Navy.

For the first time, the voted French five-year plan—which actually represents only AEC budget—does not embrace all French efforts in the nuclear field. The French national utility, Electricité de France, which up to now has worked jointly with AEC on nuclear energy projects, will henceforth operate its own projects and finance them as well by loans. EDF presently expects to spend some 128 billion francs on its atomic power centers over the next five years. EDF-1, the first such project, is still slated to start up in 1959 (NU, July '57, 27).

Official EDF plans call for 800-850 Mw nuclear installed capacity by 1965 (NU, May, '57, 21), but this goal is almost certain to be

raised now that France has ratified the Euratom treaty. Reported new goal is 2,500 Mw by 1965, 4,000 Mw by 1967.

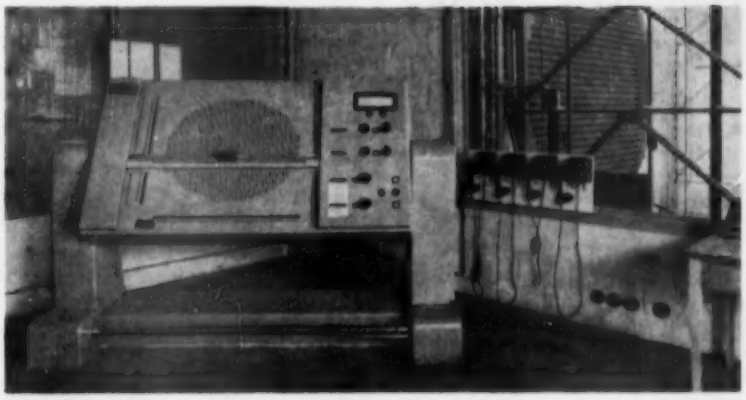
Enrichment Plant Seen

Much of the Assembly debate on the five-year program centered on a 25 billion franc item earmarked as the first installment for the building of an isotope separation plant, whose total cost is estimated at 60-billion francs ($171-million). It now seems likely that France will go ahead with the construction of this enrichment facility, despite the possibility that Euratom may schedule a similar project.

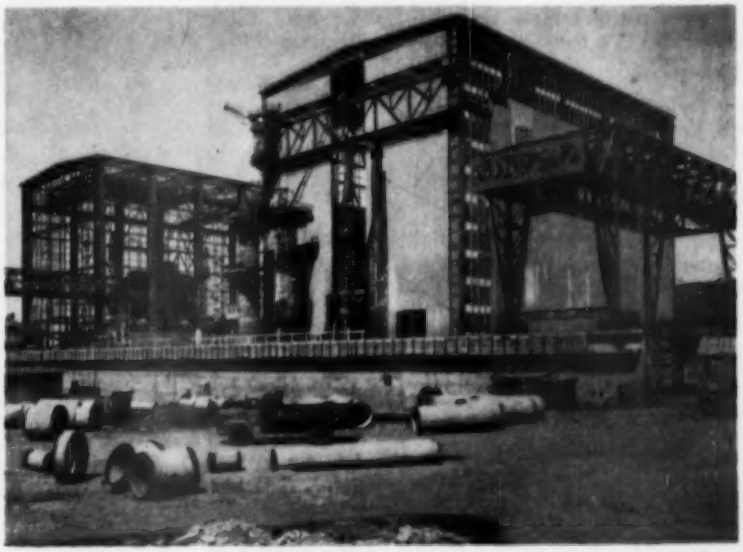
Commenting on the project in the National Assembly, M. François-Bénard, new State Secretary for Atomic Affairs, put the government's position this way: "The United States admittedly has offered supplies of U^{235} to European nations, but under conditions which limit its use and which can be cumbersome. Thus, though France can look to the U. S. for the fueling of its reactors, it is nevertheless indispensable that France have its own source of U^{235} which will assure it of its independence and its security when it comes to working on certain prototypes and for marine propulsion."

The new French AEC five-year program provides for construction of several experimental and testing reactors, not all of which have been detailed. Work has already begun on certain announced projects, such as the two swimming pools—Mélusine and Triton—and another low power pile—Minerve—which is to be used in reactivity studies (NU, Dec. '56, R9). French officials, while admitting the inevitable use of concentrated fuel for marine propulsion, nevertheless have decided to move ahead with a marine reactor project that will use natural U and will be moderated and cooled by pressurized water.

Marcoule rises in Rhône valley



G1'S LOADING-UNLOADING CONTROL PANEL overlooks actual reactor's loading face, which it simulates (cf photo NU, April '56, 22)



'STEEL CATHEDRALS' OF G2 (foreground) AND G3 near completion. Outside covering of G3 building has been completed since photo was taken, and final two heat exchangers for G2 installed beside two shown at left center; two of G3's four exchangers erected. Each is 106 ft high, 9 ft 10 in. dia, weighing 110 tons

PLUTONIUM EXTRACTION PLANT, center, is in last construction phase; to left is a plutonium laboratory

ROUNDUP

Reactor News

AEC DETAILS REACTOR PROGRESS

Here are highlights of new developments in the nation's reactor program, as reported, in AEC's 22nd semiannual report:

• The Navy Board of Inspection and Survey that accepted *Seawolf* "for restricted service" also recommended "replacing her sodium plant with *Nautilus*-type pressurized water reactor."

• Experimental plutonium fuel elements for the Materials Testing Reactor were fabricated and tested; subsequently they were added to the reactor core and used as fuel elements.

• Steady-state boiling tests with Borax-4 at atmospheric pressure were carried out with power levels as high as 2.6 Mw; "oscillations in reactivity levels were evident at higher power, but the general evidence indicated that the reactor was much more stable than anticipated."

• Component and equipment mockup tests at Argonne for the second experimental breeder "have demonstrated the technical feasibility of remote handling mechanisms and other novel features of the EBR-2 design; H. K. Ferguson has completed preliminary architect-engineer studies.

• Both the Homogeneous Reactor Test at Oak Ridge and Los Alamos Power Reactor Experiment-2 are expected to go critical late this year.

• Work is under way at Savannah River on a pressurized heavy-water power reactor.

• The Organic Moderated Reactor was loaded and was scheduled to go critical as this goes to press.

U. K. OPTIMISM ON CALDER STILL GROWING

In its third annual report, the British Atomic Energy Authority confirms its great optimism on development of the Calder-type gas-cooled graphite-moderated reactor: "It continues to show even greater potentialities than at first thought," says AEA chief Sir Edwin Plowden. Highest priority is going to expediting UO_2 ceramic fuel development and fabrication of beryllium canning material, to raise fuel temperature from 400 to 600° C—enough to up electric output from a two-reactor station from 300 to 800 Mw. AEA admits the original concept of three successive stages of development has been officially abandoned, and building of a prototype sodium-cooled graphite unit is in doubt.

SRE MAKES CURRENT

On July 12 the Sodium Reactor Experiment, which had been making neutrons since April 25 (NU, May '57, 26), made its first kilowatts. Fed over Southern California Edison's distribution lines, it was the first power from a non-military reactor distributed by a private utility company (March '56, 24; Nov., R6). Atomics International, which built and is operating SRE for AEC, hopes to be at full power—6.5-Mw—late this year; a level of 1 Mw electric has been reached thus far.

APPR PASSES 700-HR TEST

Final test of the Army's Ft. Belvoir package power reactor, a 700-hr endurance run with 40 hrs maximum downtime allowed, was a success with only 8 hrs shutdown taken; rate of electricity generation exceeded design output for over 600 hrs, and 1,000,181 kwh were produced (*see foldout facing p. 60*).

AI SELLS RESEARCH UNIT IN ITALY

The Centro di Studi Nucleari Enrico Fermi of the Politecnico in Milan has bought a 50-kw solution-type research reactor from Atomics International, which is building similar units for Tokyo, Copenhagen, Frankfurt and Berlin. The Fermi center will cost $800,000, including $320,000 for the AI reactor.

B&W OFFERS BIG POWER DESIGN

A 133-Mw pressurized water power plant designed to meet the requirements for foreign nations' utilities now in the market was announced by Babcock & Wilcox during the visit of the 60-man Euratom group (see p. 27). Fueled by slightly enriched uranium, the reactor would deliver 2-million lb/hr steam at 449° F, 420 psi saturated; power output could be increased by use of a conventionally-fired superheater.

6.5 MILES OF TUBING FOR CON ED

Makeup water for Con Edison Indian Point reactor will be provided by two 44-ton Griscom-Russell evaporators 65 ft long, 8 ft dia, containing 6½ mi copper-nickel tubing. Each unit will produce 65,000 lb/hr vapor.

EVALUATION CENTER AT WALTZ MILL

Westinghouse has established a reactor evaluation center at Waltz Mill, Pa., where its materials testing reactor is under construction (NU, July '57, 25). Centered about a critical experiment facility, the center will "check out reactor calculations and the value of various types of control rods in prototype cores for power reactors."

WESTINGHOUSE EXPANDING FUEL FACILITY

The twice-enlarged nuclear components plant at Cheswick near Pittsburgh is being expanded again: Westinghouse is adding 24,000 ft² starting this summer, for manufacture of core components and complete core assemblies. By year's end Cheswick will employ 275.

U. K. CLAIMS LEAD IN REACTOR SALE VALUE

Moneywise, Britain is ahead of the U. S. two-to-one on nuclear power plants exported, according to the *Financial Times* of London. U. K. firms, it says, have sold or are negotiating sale of five plants (in Australia, Italy, Japan, and two in Germany) worth £54-million ($151-million), while the U. S. is credited with six sales or solid prospects (in Belgium, Brazil, Cuba, Italy, Mexico and Dominican Republic) worth £20-million ($56-million). One joint Anglo-American sale was made to Germany. On the other hand the survey gives the U. S. a 21-6 lead in research reactor sales. British manufacturers expect foreign nuclear plant orders to reach $475–540-million by end of 1958, $840-million by 1960, $1,400-million by 1965, the *Financial Times* says.

World News

International Agency Comes into Being

The International Atomic Energy Agency became a reality July 29 when President Eisenhower signed the instrument of ratification. Eighteen ratifications including three among U. S., U. K., USSR, France and Canada were required; Britain ratified earlier that day. Total acceptances are up to 21 with Denmark, Dominican Republic, Honduras, India, Israel, Japan, Portugal, Sweden and Turkey having come in last month (NU, July '57, 22).

British to Train South Africans

Britain will help the Union of South Africa develop a nuclear program by training her scientists under a new agreement. Two Afrikanders will do research at Harwell on heavy water production methods, with a view to its production in the Union.

Atomic Tie-in at Scottish Hydro Plant

Britain's biggest hydroelectric project, a $68.6-million, three-station system in the River Awe catchment area, will have facilities for using surplus energy from nuclear power or high efficiency steam stations. Nights and weekends when system load is low, the generating plant at Cruachan (which will include Scotland's first large-scale pumped storage hydroelectric development) will absorb surplus energy from A-plants by pumping water from Loch Awe to a high-level reservoir with a head of 1,300 ft.

Ecosoc Debates Nuclear Power

At its 24th session, the U. N. Economic and Social Council discussed a detailed report prepared for it on nuclear power prospects (NU, July '57, 19), and called for further studies on energy resources and technical assistance needs, with recommendations for action by it early in 1959. Ecosoc rejected a Soviet proposal asking the U. N.'s regional economic commissions to carry out peaceful atomic development projects regionally, on the ground this should await establishment of the International Atomic Energy Agency in October.

Mitsubishi Seeks Westinghouse Tie

A 15-year technical tie-up for building nuclear-powered ships with International Westinghouse Electric Co., has been negotiated by Mitsubishi Electric Mfg. Co. In applying to the Japanese government for approval, Mitsubishi says its contract with Westinghouse calls for initial royalty fees of $1-million over two years, would permit production of experimental, power-generating and ship-use reactors, besides all materials needed for their operation.

France Finds Uranium in Africa . . .

After long silence, French officials confirmed reports of an important uranium strike in Gabon, French Equatorial Africa. It is said to be rich stuff.

. . . and Germany in Its South

Four uranium finds in Bavaria and two in Baden-Württemberg are reported, and said to be economically exploitable. . . . A mining firm, Gewerkschaft Brunhilde, plans Germany's first U-ore dressing plant, to process 5,000 tons/yr, at Ellweiler in Rheinland-Pfalz state. Costing $120,000, it will be expanded later to handle 20,000 tons/yr.

British Schedule Two Big A-Tankers

A 65,000-ton nuclear tanker is already in the design stage in Britain and will be built on the Clyde by a new industrial combine. John Brown & Co. Ltd., Clydebank shipbuilders, and the Hawker Siddeley Group Ltd. have—as forecast (NU, June '57, 27)—pooled their resources to form Hawker Siddeley–John Brown Nuclear Construction Ltd. Studies on the big ship have been underway for more than a year. "One thing we have established," said Sir Arnold Hall, technical director of the Hawker Siddeley group, "is that a nuclear-powered tanker is capable of delivering oil to Britain cheaper than the conventional tanker." The new company, capitalized at $1.4-million, will carry out other nuclear power projects, perhaps including nuclear aircraft. . . . Earlier, Babcock & Wilcox Ltd. and Cammell Laird & Co., Birkenhead shipbuilders, announced plans for a nuclear tanker, also of 65,000 tons (NU, May '57, 27). The two have been collaborating for 16 months on this study.

Italy May Nationalize Atom

A bill envisioning nationalization of production of nuclear power and of fissionable materials is now before the Italian parliament. It establishes the conditions under which the State will participate in assisting private enterprise in developing nuclear activities outside these two fields, and establishes an inter-ministerial commission for determining and executing policy. The bill may be amended considerably before being voted on in final form, but it is held unlikely that it will be defeated. Chances of a full-dress debate at this session, before the parliamentary summer vacation, are practically nil, and no action may be taken until a new parliament meets after the elections set for spring of 1958. Meanwhile preliminary discussions between the World Bank and the National Electronuclear Authority are reported to have been completed. The Bank is understood to have agreed in principle to help finance Italian nuclear development, but details are closely guarded.

Dutch Plan a Calder-Type Plant

A 150-Mw Calder-type power plant is planned for North Brabant province in south-central Holland, to be in operation by 1962. The reactor and most of the components will be purchased abroad. The station is part of the Netherlands' 2,600-million guilder ($684-million) nuclear program for 1962–5, will cost about 200-million guilders ($52.6-million).

U. S. Heavy Water to Sweden, Australia

Sweden will receive 28.6 tons of heavy water from AEC for use in the prototype space-heat reactor being installed near Stockholm (NU, Dec. '56, R10). Cost comes to $1.6-million at $28/lb . . . Australia will receive 11 tons D_2O for its high flux reactor building near Sydney (NU, Oct. '56, R7). Total cost is $616,000. To date, AEC has sold 217 tons of heavy water under the Atoms-for-Peace program.

RWE Picks Site

Gross-Welzheim on the Main river will be the site of the 15-Mw power reactor, Germany's first, to be built for Rheinisch-Westfälische Elektrizitätswerke of Essen (NU, May '57, 27).

News in Brief

Three-Industry Atomic Team Formed

General Aniline & Film Corp., Emerson Radio & Phonograph Corp., and Revere Copper & Brass Corp. have submitted a plan to AEC for a nuclear radiation reactor project. Known as the CEM Group (Chemical, Electronics and Metallurgical industries in partnership), it will aim to use radiation in lab experiments and commercial applications.

OEEC Energy Group Meets

The nine-member Energy Advisory Commission of the Organization for European Economic Cooperation held its first meeting in Paris last month and took up national energy policies and Europe's growing energy needs.

British Complete Fusion Apparatus

Harwell has completed a "fundamental" apparatus for investigating fusion reactions. Britain claims the apparatus will put it "ahead in the world race to achieve a controlled thermo-nuclear reaction." Although operating data, size and cost were not disclosed, it was reported by Sir John Crockcroft, Harwell's research director, that the equipment would be used to heat hydrogen isotopes to about 100-million degrees C at which fusion reactions can be detected. Metropolitan Vickers Electrical Ltd. was prime contractor.

Birthplace of Atomic Energy Doomed

The west stand of Chicago University's Stagg Field, on the east side of Ellis Ave. between 55th and 56th streets, will be razed this month. Here, on Dec. 2, 1942, was born the atomic age when, in a squash court built under the stand, Enrico Fermi's first uranium-and-graphite pile went critical. The stand, not used since Chicago withdrew from intercollegiate football in 1939, is now structurally unsound. A plaque commemorating the first chain reaction will be placed on a temporary base on the cleared site, and later installed permanently when the site is again used.

Texas A&M plans nuclear center

A nuclear center embracing a research reactor, a gamma radiation facility and a particle accelerator is contemplated at Texas A&M College. Proposals will soon be submitted to the college's board of directors. The center is to be a part of the Texas Engineering Experiment Station, a division of the college. If approved, the center will offer both research and educational programs. According to Richard E. Wainerdi, the Station's nuclear coordinator, the center most likely will include a 1-Mw swimming-pool reactor, a medium-size Van de Graaff accelerator, radiation sources and hot labs; and would also house the Aerojet-General Nucleonics training reactor to be installed by mid-September. Aims of the center, Wainerdi says, are to provide a personnel-training facility required by Texas' growing nuclear industry, and to do research for industry, agriculture and medicine.

Westinghouse Also in Fusion Work

On the heels of General Dynamics and General Electric (NU, July '57, 24), Westinghouse announced its part in the Project Sherwood drive for controlled fusion power. Centering on ultra-high vacuum techniques, Westinghouse work includes development of ultra-high vacuum components and pumping systems; research to understand and control factors limiting production of high vacua; study of relative effectiveness of alternate methods of producing ultra-high vacua, and design and fabrication of vacuum components and systems.

Homestake Plans Uranium Mill

A completely automated mill uranium run by a single operator and capable of processing 850 ton/day will be built by Homestake New Mexico Partners at Grants, N. M. (NU, June '57, 28). Situated in the Ambrosia Lake district, the mill is a joint venture of Homestake Mining Co. and Rio de Oro Uranium.

Late '58 Completion for Lockheed Plant

Lockheed Aircraft Corp. anticipates having its nuclear aircraft research laboratory near Dawsonville, Ga., (NU, May '56, 22) operating by the end of 1958.

Two Firms Join Research Programs

San Diego Gas & Electric Co. will take part in General Atomic's research program on nuclear power systems, comparing various proposed reactor types and assisting in designing specific reactor facilites . . . In Cleveland, Crawford Fitting Co., tube fittings and valves manufacturer, has become the eighth firm to join the Case Industrial Nuclear Center.

Two Centers Offer Radiation Services

A 2-Mev Van de Graaff accelerator at High Voltage's Burlington, Mass., plant can be rented for testing effects of radiation on materials or for actual production purposes. In the West, Applied Radiation Corp. also has a customer service irradiator center at Walnut Creek, near San Francisco.

World Radiation Hazards Reviewed

Radiation dangers stemming from industrial uses of nuclear energy were given top priority at the first conference, July 29–Aug. 1, of the International Organization for Standardization's nuclear group. Meeting in Geneva, the 19 IOS member nations, including the U. S., UK and USSR, considered establishment of worldwide safety standards.

Florida State Plans Accelerator

The nuclear radiation center planned by Florida State University, Tallahassee, will have a 10-Mev Van de Graaff tandem accelerator installed by late 1959, comprised of two 5-Mev accelerators end-to-end.

Euratom Group Tours U. S. Facilities

To receive first hand orientation on pressurized and boiling water reactors, a group of 50 industrialists and government officials representing Euratom countries visited more than a dozen AEC and private industrial sites during July. Interested in the problems of setting up large power reactor complexes, the group met with nuclear engineering, power and manufacturing firms.

Tennessee Sets Up Nuclear Board

An eight-man state nuclear advisory committee has been established in Tennessee, with Howard P. Preston, president of the Hamilton National Bank, Knoxville, as chairman.

Chamber A-Group Renames Head

Lewis M. Smith has been reappointed chairman of the committee on commercial uses of atomic energy, Chamber of Commerce of the United States. He is president of the Alabama Power Co., Birmingham.

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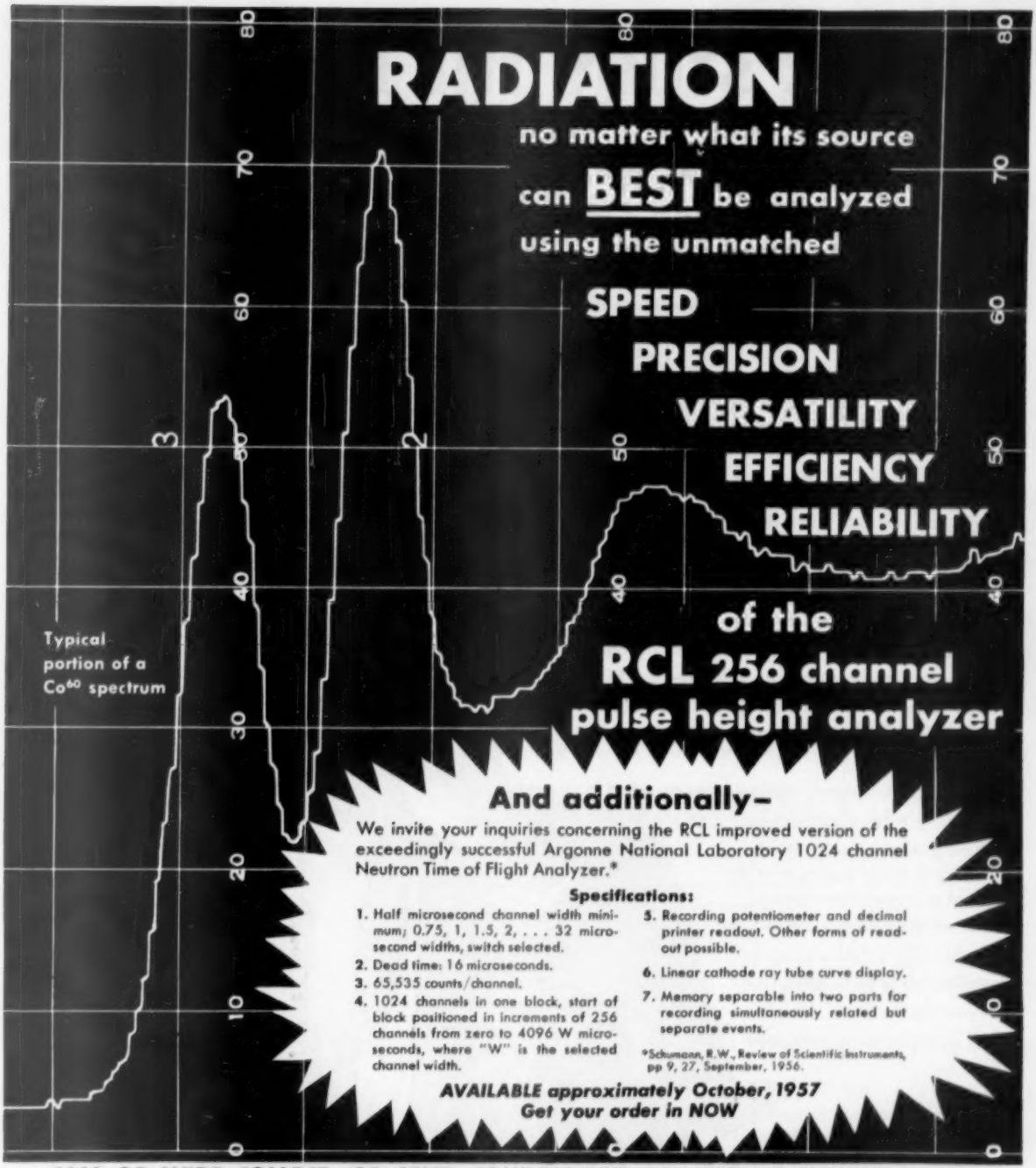

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*Schumann, R.W., Review of Scientific Instruments, pp 9, 27, September, 1956.

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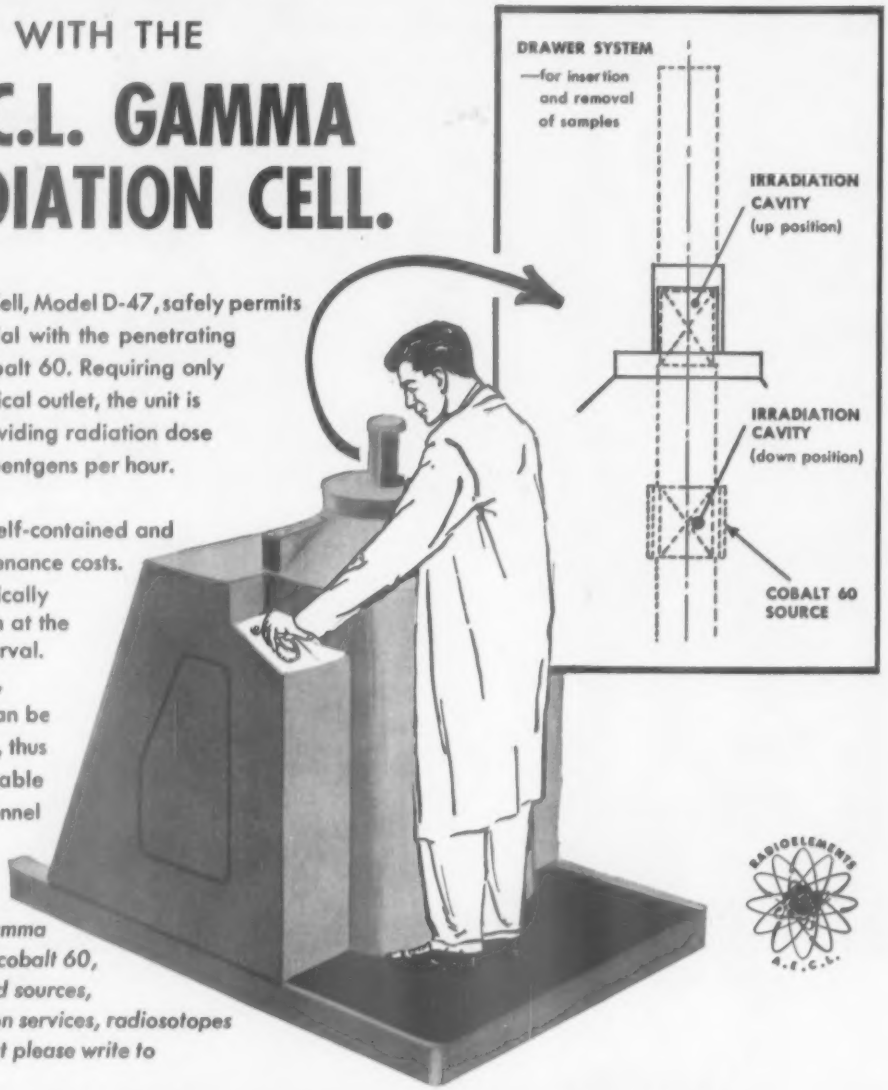

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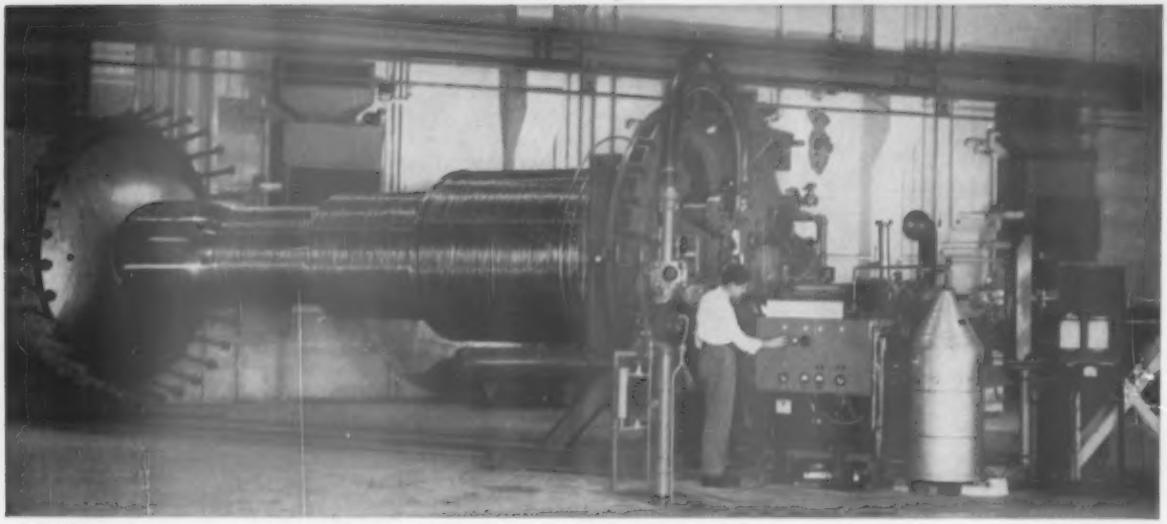

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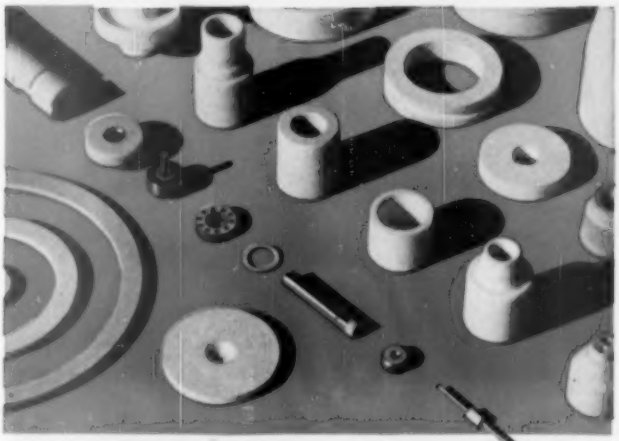

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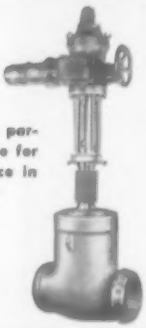

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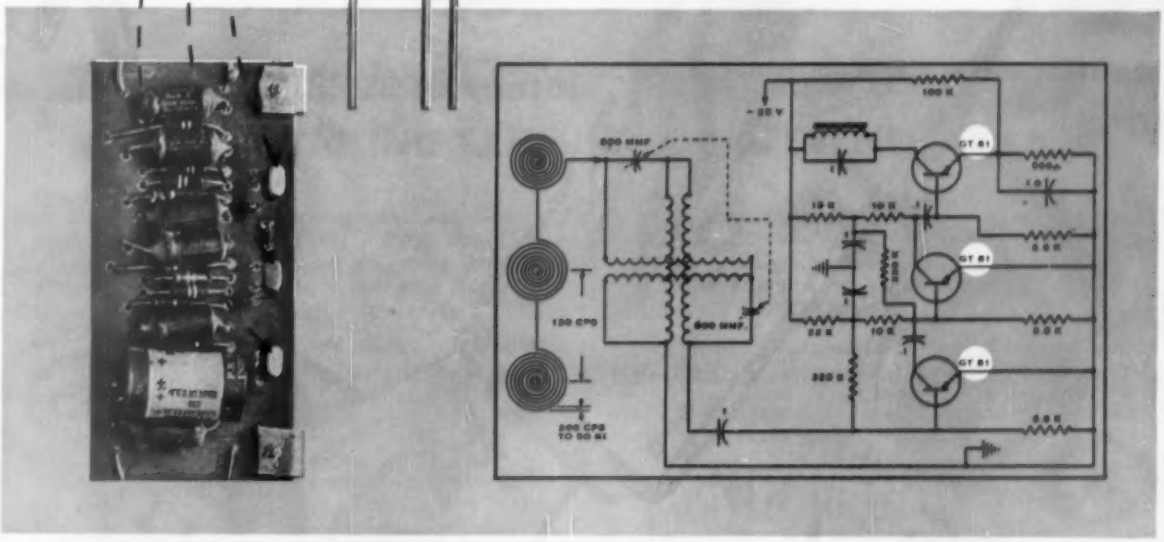

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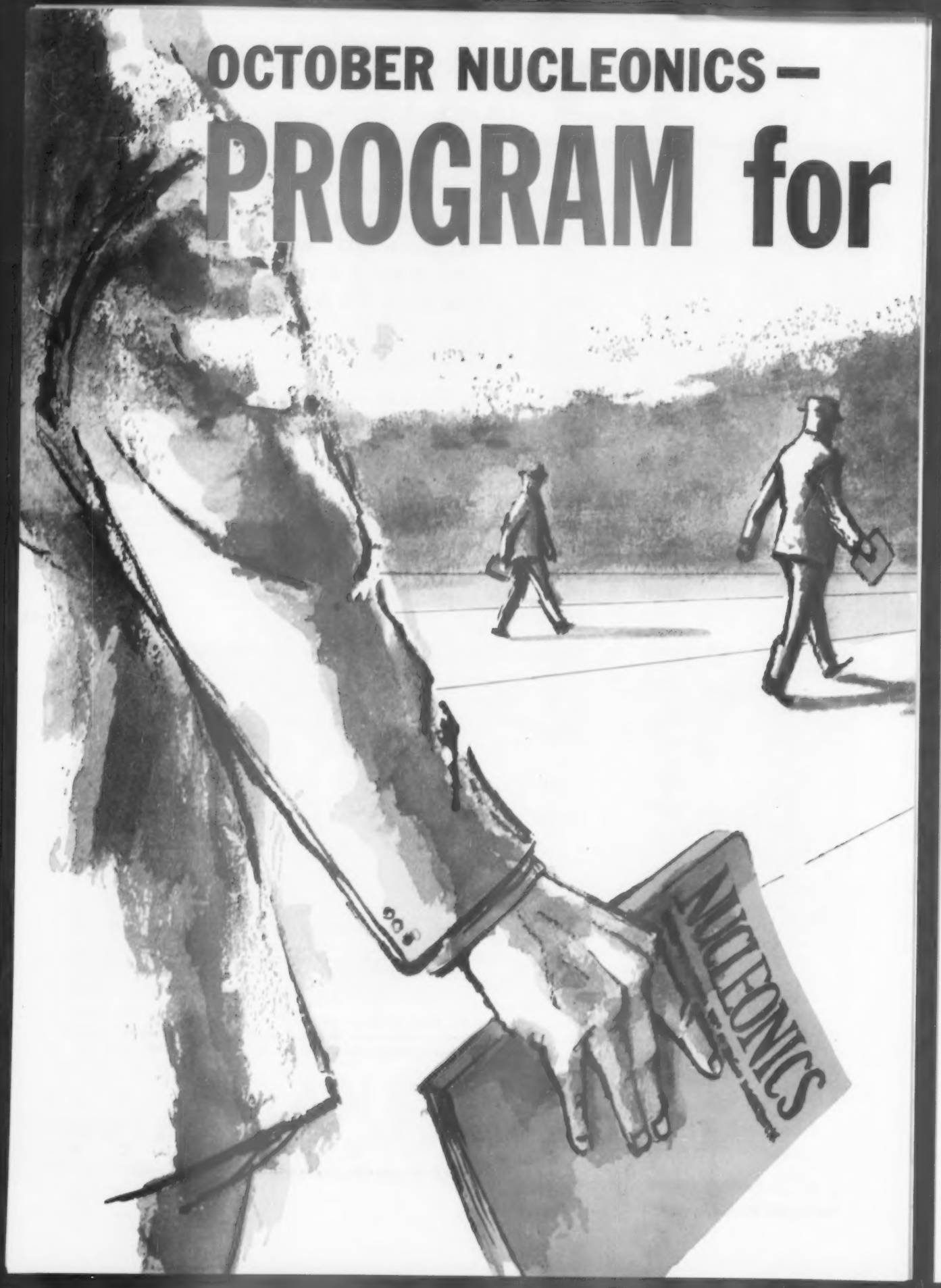

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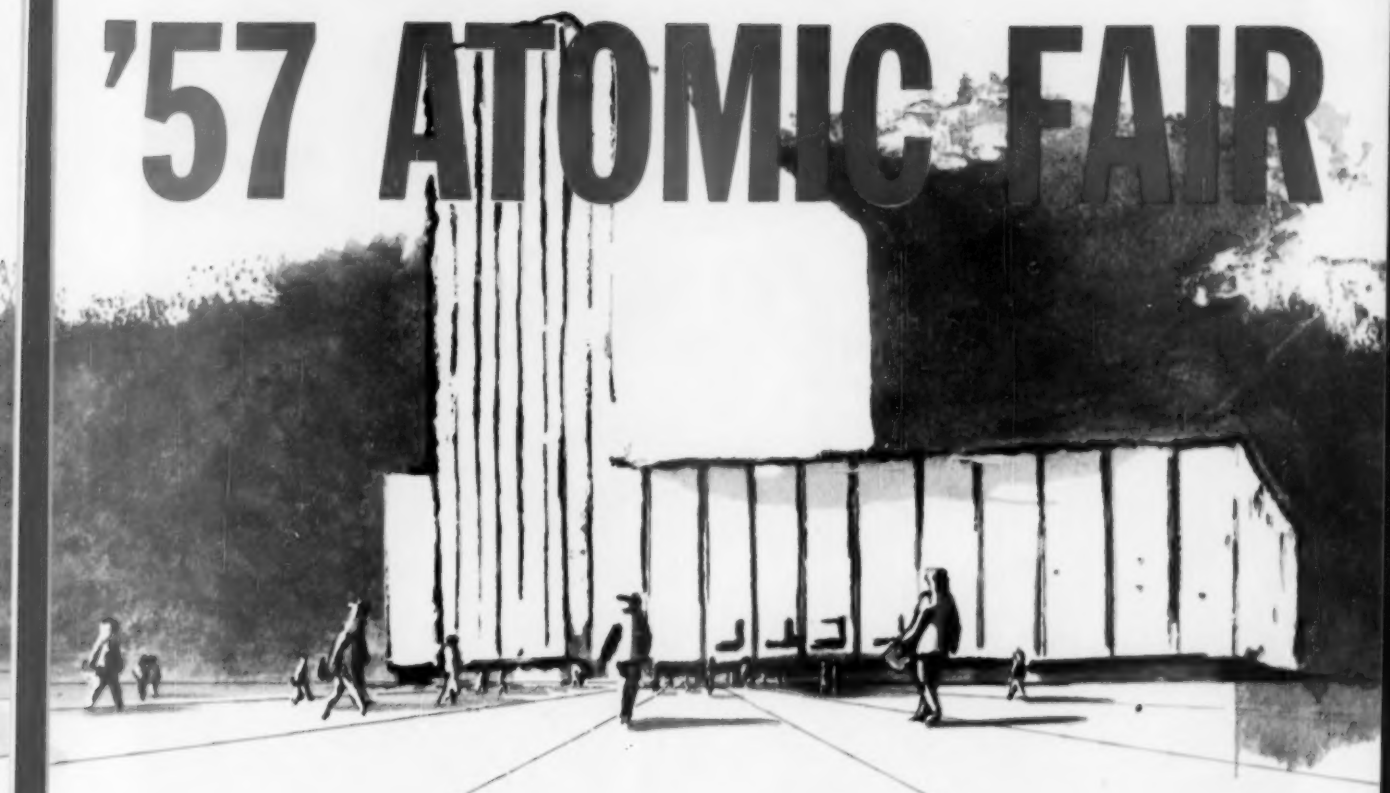

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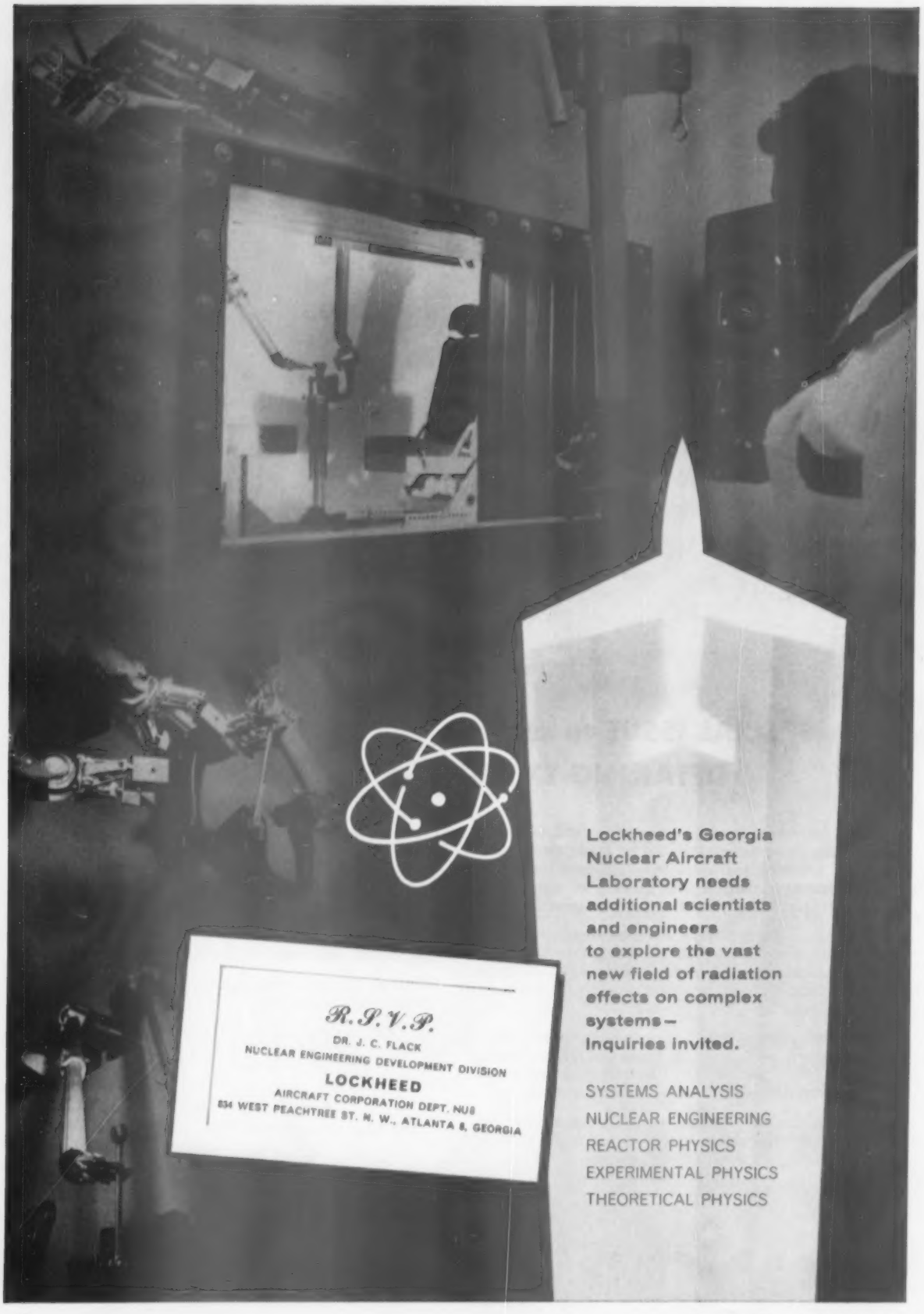
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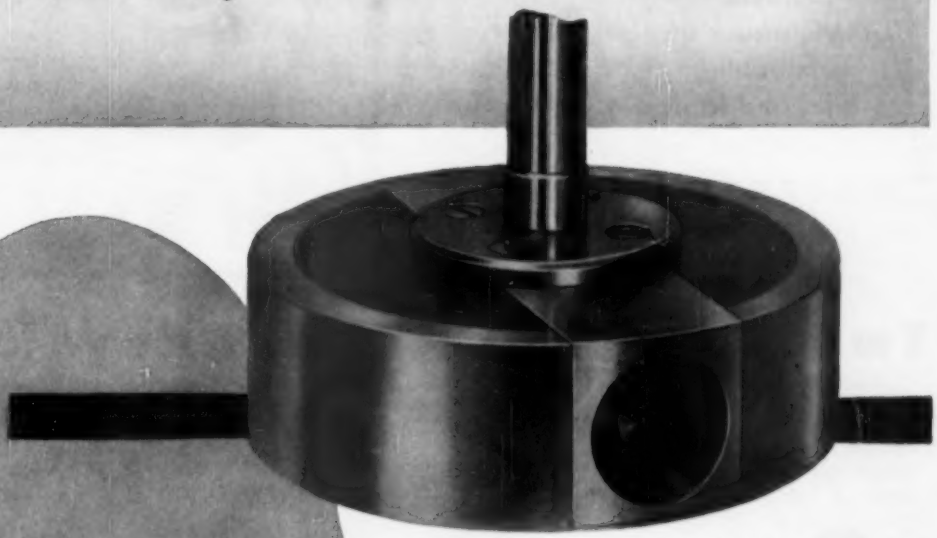

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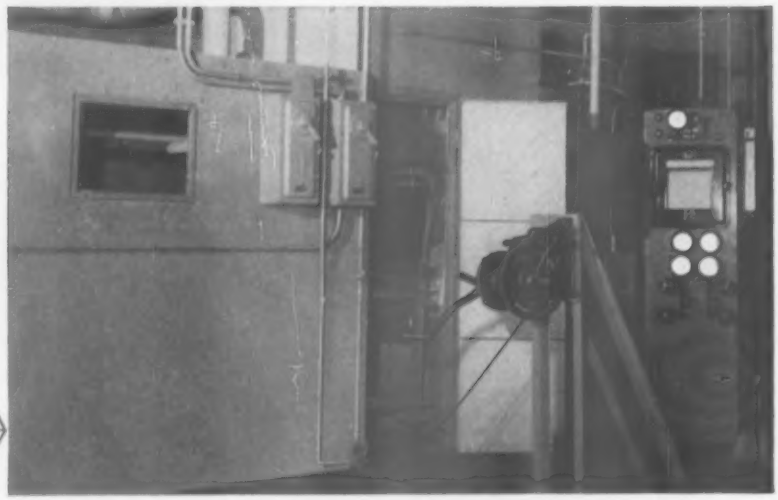

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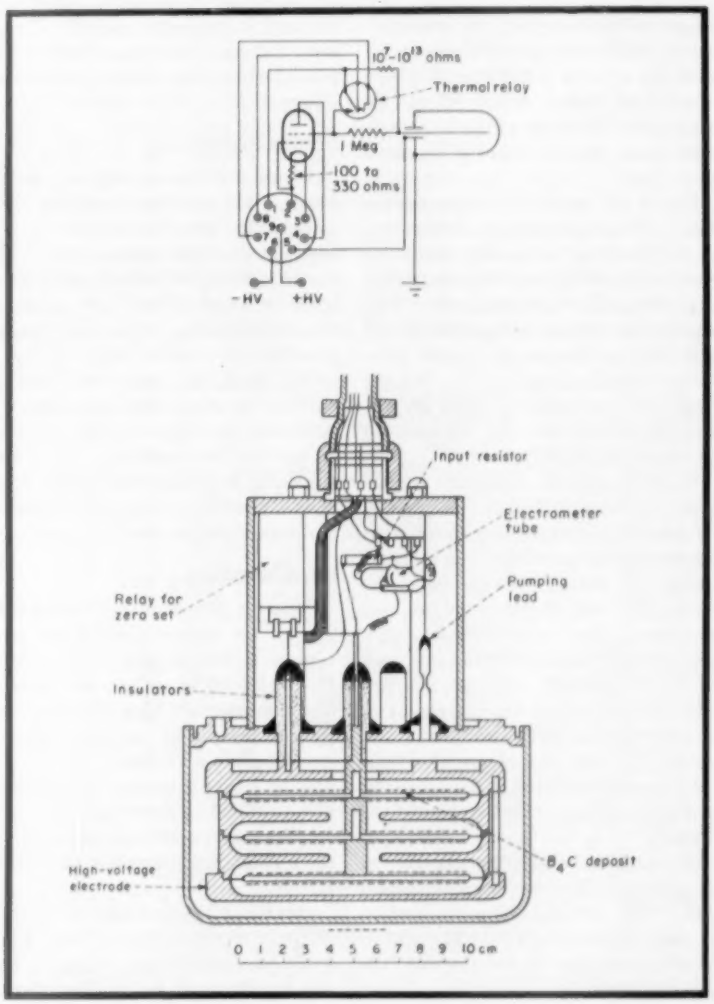
By J. WEILL
Commissariat à l'Energie Atomique, Paris, France



REACTOR OPERATION requires servomechanisms and assemblies of instruments for both nuclear and nonnuclear measurements. Control can be automatic or manual. We in France have developed a variety of instruments and mechanisms for this purpose. We have automatic control systems that combine power-proportional and reactivity-proportional signals. They move both regulating rods and compensation rods designed to compensate for temperature effect and poisoning from burnup. We have also developed ionization chambers with compensation for gammas and shielding to be used with them so that they can be used over 9 decades of neutron flux. Little has been published in American journals concerning these developments (*1*, *2*).

Automatic Control

Our automatic control system consists of (a) a sensing system to furnish an error signal and (b) a remote-control system in which a signal causes movement of the control rods. The signal can be the error signal itself or a more complicated function.

Principle. We use a power-error signal modified by a signal proportional to the reactivity. Thus the signal injected into the control system is

$$U = A(P_0 - P) - BR$$

FIG. 1. Boron-lined chambers have electrometer tubes and input resistors sealed in. Thermal relay permits short-circuiting resistor for zero adjustment

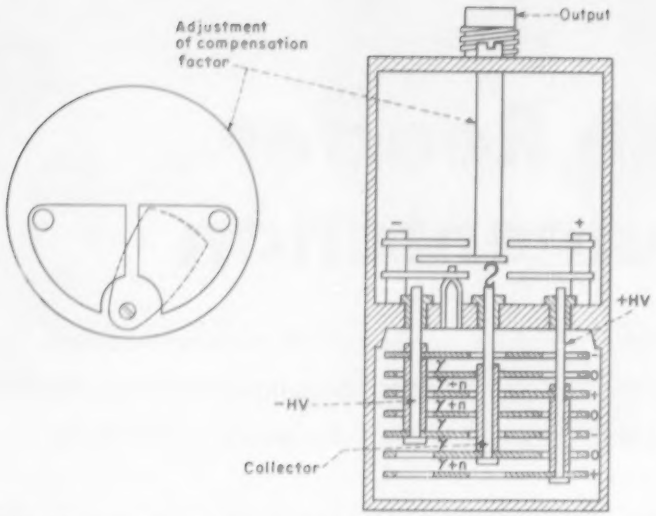


FIG. 2. Compensated ion chamber has sections sensitive only to gammas bucking similar sections sensitive to gammas and neutrons. Top section provides adjustment of gamma compensation

where P_0 is the demand power, P is the actual power of the pile, A and B are the two injection coefficients, and R is a signal proportional to the reactivity $\Delta\rho/\rho$ (*3*).

Error signal. For a power measurement we usually use a system consisting of an ionization chamber followed by a d-c amplifier. The voltage output of the amplifier is proportional to the reactor power, and it is compared with a reference voltage representing the desired power. The difference between these two voltages is the power-error signal. We use two types of error signal corresponding to coarse and fine measurements of power. Switching between the two signals is effected automatically as soon as the magnitude becomes less than a given value. To measure reactivity we use an automatic potentiometer system that is described later.

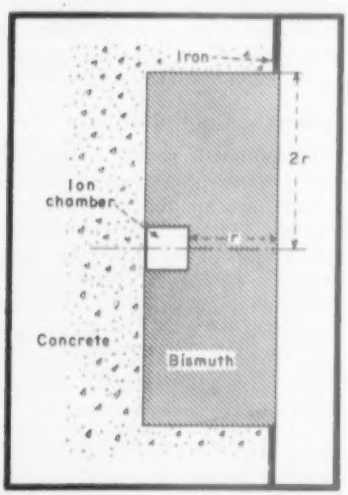


FIG. 3. Bismuth shield attenuates gammas more than neutrons and extends useful range of chamber to 9 decades

Xenon and temperature compensation. Xenon poisoning and elevation of temperature generally introduce negative reactivity greater than that available in the regulating rods. This suggests the use of compensation rods with their position coupled to the automatic control system (*4, 5*). We use rods with a speed in reactivity per second that is less than half the speed of the regulating rods.

Coupling to the automatic control system is accomplished in a simple way by contacts corresponding to different regulating-rod positions. As a regulating rod moves through its entire stroke, five sets of contacts close, one at a time. These contacts correspond, respectively, to the following five positions: (1) high end of stroke, (2) high end of effective stroke, (3) center of effective stroke, (4) low end of effective stroke, (5) low end of stroke. Normally a regulating rod in an automatic system is maintained between positions 2 and 4.

The high-end-of-effective-stroke contact initiates the rise of a compensation rod. The low-end-of-stroke contact starts the descent of one. The center-of-effective-stroke contact stops the rise or descent.

As soon as a compensation rod reaches the limit of its stroke the high-end-of-stroke and low-end-of-stroke contacts are switched to control the action of another compensation rod, and so on through all of the compensation rods. The order in which the compensation rods come into action is selected before the system is placed in operation.

Manual Control

For manual control we use a servomechanism to adjust control rods. The signal portion of the system has a fine selsyn transmitter and a coarse one. Their sensitivities are in the ratio 1:20, and they are located at the control desk.

The follower system at the reactor includes fine and coarse selsyn receivers. These are coupled mechanically to the drive motor of a drum. Suspension ribbons for the control rods are rolled on the drum. The motor is controlled through a magnetic amplifier by the error voltage that appears between the selsyns when their angular positions are different.

Scram Procedure

After a fall of the safety rods the descent of the compensation rods is effected at the end of a time interval controlled by a time-delay circuit. This descent cannot be halted until the rods have reached their low positions. Thereafter raising of the safety rods is possible only when a certain number of safety interlocks have been closed according to the startup sequence. In particular the compensation rods must be in their low positions. Only after the safety rods have reached the upper ends of their strokes can the regulating and compensation rods be raised.

Ion Chambers

First in the chain of instruments needed for reactor control are those concerned with detection of neutrons. For that purpose we use ion chambers and thermopiles. The chambers have the inconvenience of sensitivity to gammas, but we reduce that considerably by means of gamma compensation and preferential shielding. The thermopiles are insensitive to gammas, but their long time constants make them inappropriate for reactor control.

Our BF_3-filled chambers have a sensitivity of 10^{-15} amp/n/cm²/sec for each cubic centimeter of gas volume. They are mainly used for reactor startup.

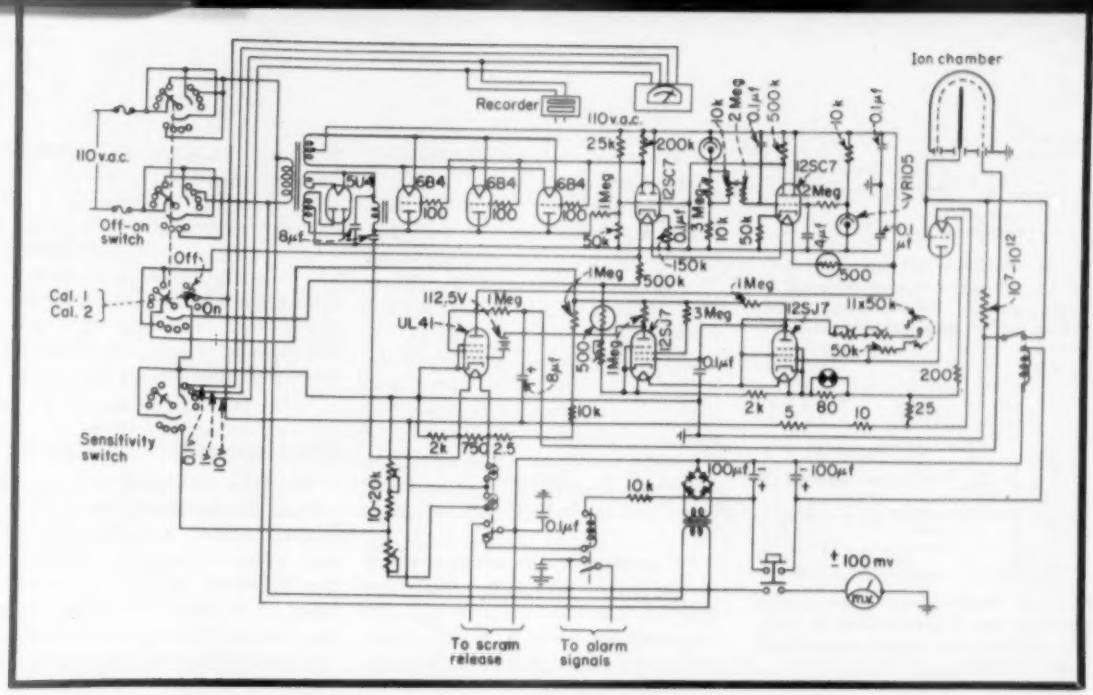


FIG. 4. Three-stage amplifier has 100% negative feedback and produces current gain in ratio of input to output resistors

Boron-lined chambers (Fig. 1) have alternate plates with either solid boron or B_4C deposited with a thickness of 1 mg/cm². Natural boron gives a sensitivity of 5×10^{-15} amp/n/cm²/sec, and boron enriched in B^{10} gives about five times this sensitivity (*6*).

The electrometer-tube preamplifier circuit is generally sealed in the same envelope as the ion chamber, as shown in the figure. Also in the sealed envelope are the input grid resistor and a relay that permits short-circuiting the resistor for the purpose of zero adjustment. The relay can be magnetic or thermal. We prefer the thermal relays because the magnetic fields of the other type frequently alter the current of the electrometer tube.

Gamma compensation. To measure neutron fluxes in the presence of intense gamma fields we have developed the compensated ion chamber of Fig. 1. To subtract out the effect of the gammas one operates two chambers in opposition (*6*). One is sensitive to neutrons and gammas, the other to gammas only. The two types have collecting potentials of opposite polarity.

Several pairs of chambers are contained in the same envelope, as shown in the figure. The component chambers are formed by two alternating sets of plates. Those with a boron deposit respond to neutrons and gammas, and those without the boron coating, to gammas alone. The numbers of elementary chambers of the two types are the same.

The amount of gamma compensation is adjusted by means of the special gamma chamber shown at the top of the assembly in Fig. 2. The compensation control consists essentially of a circular sector of several square centimeters of area. It is connected to the output terminal for the collecting electrode and moves between two pairs of plates, one mounted on the positive high-voltage terminal and the other on

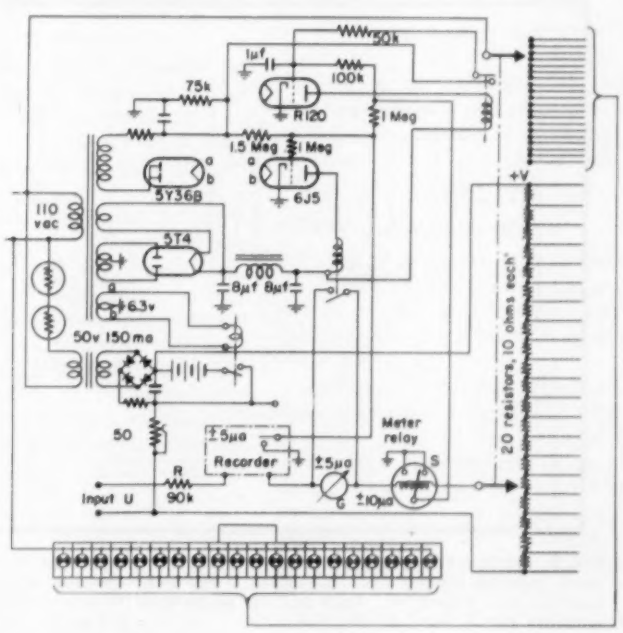


FIG. 5. Vernier system displays reactor power with pilot-light system to indicate power range and sensitive galvanometer to indicate position within range. Regulated voltage *V* is applied to potentiometer *P* at right. Voltage to be measured, *U*, is opposed by *N* steps of a total of *n*. Vacuum-tube system closes relay to protect galvanometer when it would read off scale. Power is sum of reading of position pilot light, actuated by second contact of potentiometer arm, and reading of galvanometer

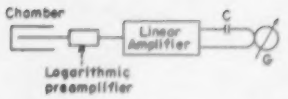


FIG. 6. Amplifier following ion chamber has voltage output proportional to reactor power. Differentiating circuit delivers current that indicates reactivity

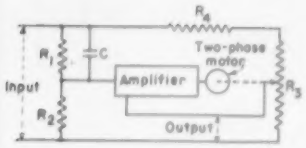


FIG. 7. Motor-driven potentiometer produces signal proportional to reactivity by combining signals proportional to dP/dt and P

the negative high-voltage terminal. Thus the net current delivered to this sector in a gamma field will be positive, negative, or zero depending on whether the larger portion of its area is between the negative plates or the positive ones.

The gamma effect can be made 300–600 times weaker in compensated chambers than it is in uncompensated boron-lined chambers. The useful range can thus be made to extend over 6 decades. To improve the gamma compensation and thus permit exploration of ~9 decades in the power range, it is necessary to interpose between the radiation field and the ionization chamber a substance that is very absorbent to gammas and not so for neutrons. We actually use a bismuth filter (Fig. 3). This filter attenuates neutrons by 1.4 and gammas by 140 for a minimum thickness (r of Fig. 3) equal to 12.5 cm. The amount of bismuth is then 425 kg.

At higher powers we shield the chamber with a removable boron curtain. This attenuates neutrons by $\sim 10^3$.

D-C Amplifiers

The ionization chambers previously described furnish d-c currents of 10^{-5}–10^{-14} amp, which must be amplified. The potential produced by passing the current through a large resistance is applied to the control grid of an electrometer tube. The output is connected through a cable to a d-c amplifier. Under best conditions the electrometer tube permits measurement of ~1 mv with an input resistance of $\sim 10^{13}$ ohms.

The amplifier of Fig. 4 has three stages and total negative feedback. Its 250-volt supply is carefully regulated so that it varies less than ±10 mv for a variation of ±10 volts in the line voltage.

The voltage gain, by virtue of the feedback, is unity. The current gain is given by the ratio of input resistance to output resistance. In this amplifier the input resistance can be as high as 10^{13} ohms, the output resistance is 10^3 ohms, and the current gain can reach 10^9.

Permutations of the series resistances at the output give four sensitivities: 0.05, 0.5, 5, and 50 volts full scale. The time constant can be adjusted for slow or fast response depending on the measurement requirements. Drift in the amplifiers that have been built is a few millivolts in 24 hr.

Vibrating-capacitor electrometers. To avoid the slow continuous drift of d-c amplifiers we transform the d-c current of the ion chamber to an a-c current by means of a vibrating capacitor. Two arrangements can then be used: a servomechanism consisting of a two-phase motor driving an automatic potentiometer, or a lock-in detector synchronized with the a-c potential furnished by the amplifier. One model built at the Commissariat à l'Energie Atomique has the following characteristics:

	Voltage	*Current (amp)*
Full scale sensitivity	10 mv	10^{-14} with 10^{13} ohms
Precision	±0.3 mv	$\pm 0.3 \times 10^{-16}$
24-hr drift	200–300 μv	$2\text{–}3 \times 10^{-17}$

Pile Monitors

We have developed several useful circuits for monitoring reactor power and reactivity. A power-vernier system yields a sensitive indication of power level in terms of a system of pilot lights that indicate the power interval and a sensitive meter that indicates the value of the power within the registered interval. To indicate reactivity we use logarithmic amplifiers, automatic potentiometers and a simple computer circuit that takes into account the influence of delayed neutrons.

Power vernier. Reactor power can be measured with an ionization chamber, a d-c amplifier and a potentiometer-recorder. Precision of the method can reach 0.3%. A more precise readout is possible with an automatic precision potentiometer (Fig. 5).

As can be seen from the figure the galvanometer spot is automatically

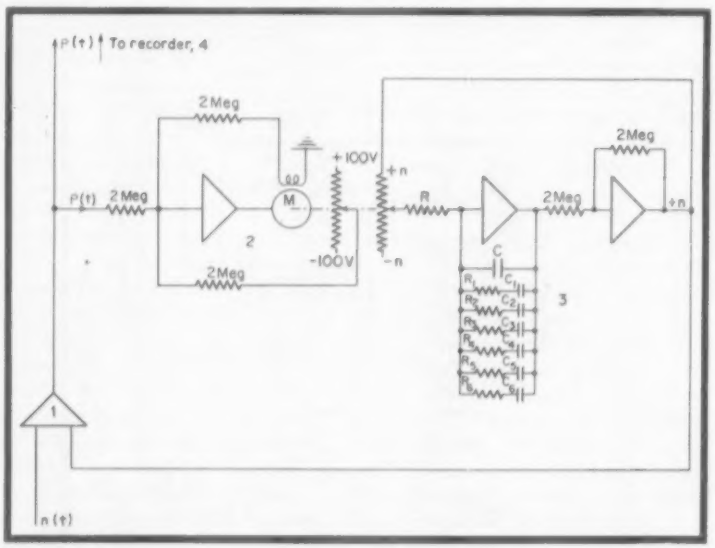


FIG. 8. Reactivity computer includes summer (1), servomultiplier with rate-proportional negative feedback (2), RC circuits to represent delayed neutrons (3), and recorder (not shown) (4). Input $n(t)$, is proportional to power level, output to reactivity $\rho(t)$

caused to return to the low end of the scale each time it reaches the high end. This is accomplished by adding one more step of an opposing d-c potential. The total number of opposing steps is indicated by an auxiliary row of pilot lights. Thus the power reading is the sum of the value indicated by the lights and that indicated by the galvanometer. The precision of the system can reach 1 part in 2,000 (7).

In the Saclay P2 reactor, where this readout is used, the power can vary from 0 to 4,000 kw. Full scale on the galvanometer corresponds to a power of ±200 kw, and one can read it to ~1 kw.

Reactivity monitor. One system for monitoring both pile power and reactivity consists of an ion chamber followed by a logarithmic preamplifier and a d-c amplifier. This arrangement is followed by a differentiating circuit and a galvanometer (Fig. 6). The output of the amplifier is always proportional to the logarithm of power, and the current through the galvanometer is proportional to the reactivity.*

In another method we use a potentiometer and a servomechanism to compute the quotient of the derivative of the power and the power itself (Fig. 7). The apparatus includes an ion chamber, a d-c amplifier, and a servo-driven recorder. The recorder has a two-phase balancing motor driving the arm of a calibrated potentiometer. The arm's displacement is a linear function of reactivity, as has been explained previously (*1*).

Reactimeter. The kinetic equations that govern power changes in a reactor can be represented by a nonlinear operator T that transforms a set of functions $\rho(t)$ representing reactivity into another set $n(t)$ representing neutron flux. Ion chambers furnish potentials proportional to $n(t)$. Reactivity can be computed with the inverse operation: $\rho(t) = T^{-1}[n(t)]$.

The operator T can be represented with an analog computer (Fig. 8). This includes (1) a small summer, (2) a servomultiplier with a rate-proportional negative feedback, (3) some *RC* coupling circuits with circuit values and time constants chosen so that they simulate the concentrations of emitters of delayed neutrons, and (4) a recorder reading the instantaneous value of the reactivity (*8*). One can choose $\pm 10^{-3}$ or 5×10^{-3} full scale.

* During a power change we have

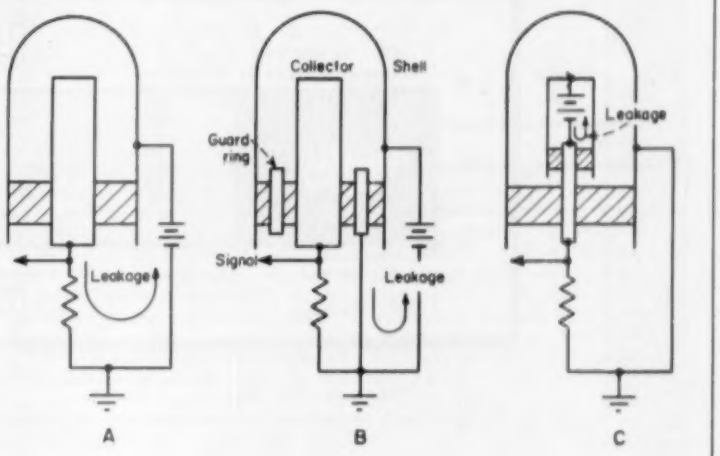
$$P = P_{0e}^{\Delta kt/l}$$

whence $\log P \propto \Delta k t$

Differentiating $d \log P/dt \propto \Delta k$

but $\rho = \Delta k/k \approx \Delta k$

Hence $\rho \propto d \log P/dt$



No Leakage, No Guard Ring

Included among French developments in nuclear instrumentation is an ionization chamber without the inconveniences of either leakage currents or guard-ring construction. The simplest of ion chambers (A) consists of a collector, a shell, a source of potential, and a means of detecting the signal—such as the resistor shown. The main difficulty is that the insulator between collector and shell is subjected to the potential difference used for ion collection, and the resulting leakage current gives a spurious signal by flowing to the collector. The guard ring of B eliminates this difficulty. With this arrangement the leakage current flows in a path that does not include the collector, and the collector insulator is subjected only to small potential differences. Still better is the arrangement of C recently developed by the author in France. The potential supply is mounted inside the collector so that the leakage current once again does not flow in the signal path. Moreover the considerable difficulties of making, mounting, and insulating the guard ring are eliminated. As a further improvement the resistor can be put inside the chamber envelope.

Nonnuclear Measurements

Typical of nonnuclear measurements are a monitor for the heavy-water level in a reactor and some glass-insulated thermocouples for monitoring reactor temperatures.

The level monitor has a platinum-tipped plumb bob hanging from a thin steel wire. The bob descends until it touches the water surface. Then an electronic circuit causes the drum holding the suspending wire to reverse and withdraw the bob. The resulting oscillation has an amplitude of ~0.1 mm. Over-all accuracy is ±0.5 mm.

The thermocouples are copper-constantan and silver-constantan. They have outputs of ~40 mv/° C. The junctions are sealed in glass, which provides good support in a high neutron flux. Total diameter including the glass insulation is ~2.5 mm. The cold junctions are brought back to the measuring apparatus, which includes a thermostat-controlled heating resistance.

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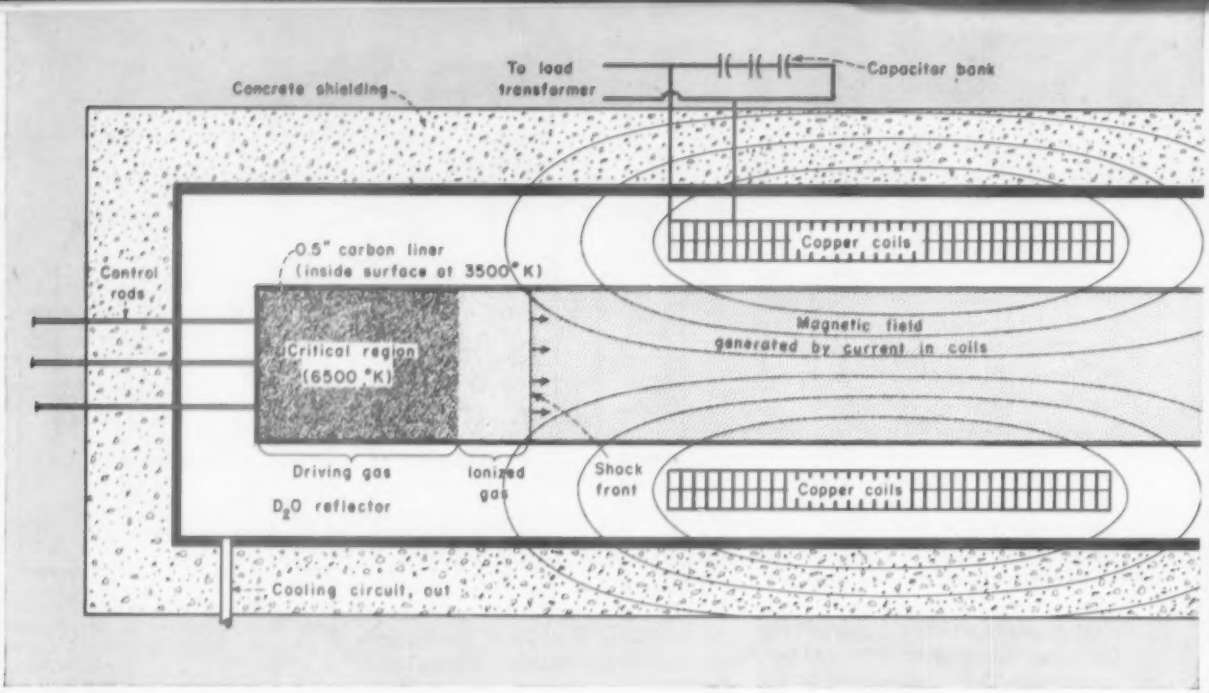

Plasma Reactor Promises

A proposed reactor converts fission energy directly into electricity by causing ionized U^{235} gas to interact with a magnetic field. Estimated operating conditions look extreme but not impossible

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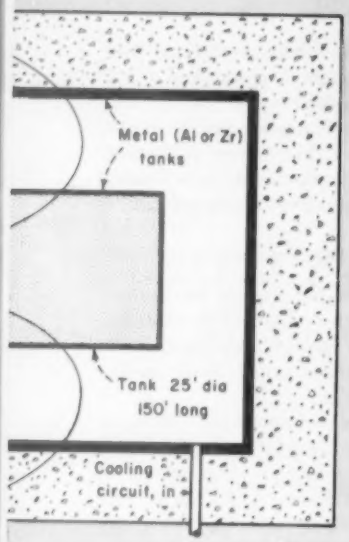
THE PRESENT DAY procedure for converting nuclear energy into electric power must have at some time stirred rebellion in the heart of every designer of power reactors. Besides being unaesthetic and unimaginative the conventional arrangement of intermediate coolant circuits, heat exchangers and turbogenerators is also cumbersome, inefficient and expensive to build and maintain. No doubt an impressive number of man-hours have already been spent by people in the field daydreaming about schemes for converting nuclear energy directly into electricity. Some have gone past the imagination stage; the atomic battery, a device that uses the energetic ions from a radioactive source to charge up a small capacitor, is an example of a successful application. So far, however, no one has advanced an economically practical scheme for making electricity directly from the fission power produced in a nuclear reactor.

With the hope of alleviating this situation we have been rash enough to put down one of our own personal daydreams on paper. Surprisingly enough our rough design calculations show that the scheme may prove to be technically feasible and possibly even economically feasible. We offer, then, for further consideration the conceptual design of a reactor that converts the energy produced in the fissionable material directly into electrical energy.

The proposed reactor is cylindrical in shape and would contain the fissionable material in gaseous form. The temperature of the gas is high enough so that part of it is ionized. The direct conversion is accomplished by having the ionized (and therefore electrically conducting) fissionable gas do work against a magnetic field. The work done against the field appears as electrical energy in an external circuit. The dynamical motion of the plasma (hot gas) is so arranged that after each interaction with the magnetic field the plasma configuration is reshaped by solid walls so that magnetohydrodynamic instabilities cannot grow from cycle to cycle.

Basic Concept

Basically the reactor is a long cylinder of refractory material surrounded at each end by a neutron reflector and moderator. The cylinder is filled with a fissionable gas (say U^{235} or Pu^{239}). The amount of gas would be adjusted so that when it is uniformly distributed the system is just below criticality. Then any disturbance causing more



CONCEPTUAL DESIGN of fission-plasma reactor. Cylindrical reaction chamber contains high temperature U^{235} gas at 1 atm pressure. Gas becomes critical when compressed at one end of cylinder. Resulting fission energy release creates shock wave driving gas to other end of cylinder where it is again compressed. Thus gas oscillates back and forth releasing fission energy at each end. As shocked gas travels along tube gas immediately behind shock front is highly ionized. Ionized gas, or plasma, through interaction with magnetic field transfers part of energy released in fission pulse to external electrical circuit. Energy appears as current induced in coil wrapped around cylinder. Energy is stored in LC resonant circuit formed by coil and capacitor bank until drawn off to external load. Carbon liner acts as thermal shield to keep D_2O temperature below boiling point. Reactor shown is minimum feasible size. Electrical power output would be 500 Mw

Direct Electric Power

fissionable material to be at one end of the cylinder than the other will result in multiplication and heating of the fissionable gas in the critical end. If the neutron-multiplication time is small compared with the time required for sound to travel the width of the critical region, then the temperature of the fissionable gas can increase by a number of times before a large fraction of the mass of the gas has been expelled from the critical end. Under these conditions a shock phenomenon will appear. The shock wave will travel from the heated or critical end down to the low-density opposite end. On the way it will pass through a magnetic field generated by a current-carrying coil surrounding the middle of the cylinder (see figure).

The figure shows the three regions that make up a typical shock wave. The shock disturbance, or shock front, is formed by very rapid heating of a volume of gas here called the "driving gas." The shock front travels away from its point of origin at some velocity greater than the speed of sound. The driving gas continues to expand and travels behind at a velocity somewhat slower than that of the shock front. There is then a disk-shaped region between the shock front and the driving gas that grows in length and travels at a velocity intermediate between the other two. This region contains the "shocked gas"—the gas that has been swept up by the shock since it started out. Characteristically the shocked gas is hotter than the driving gas. In the reactor this region of superheated gas will be sufficiently ionized to act like a conductor.

It is this disk-shaped conductor moving behind the shock that transfers energy to the magnetic field. When the disk of conducting gas enters the magnetic field it experiences a retarding pressure equal to $H^2/8\pi$ dynes/cm^2, where H is the magnetic field strength.* If the shock pressure is greater than the magnetic-field pressure, the conducting disk will be forced into the coil despite the magnetic field. When the disk moves past the center plane of the coil it feels a reverse pressure from the magnetic field that tends to expel it from the field.

During its approach, since the force on the disk is opposite to its motion, the disk does work on the magnetic field—some of its kinetic energy is transferred to the magnetic field. The magnetic field passes this energy on to a resonant condenser bank attached to the coil (see figure). As the energy is fed into the resonant circuit some of it can be drained off to do useful work, and some of it is returned to the disk through work done on the disk by the magnetic field as the disk leaves. The work done on the disk when leaving is always less than that done by it when entering. As a result the disk suffers a net loss in kinetic energy because of its trip through the coil. The energy lost by the disk appears (except for some unavoidable losses) as useful work in the external circuit.

The shock and gas flow continue beyond the coil into the opposite (so far noncritical) end of the cylinder. The flow will continue until there is considerable compression in this end. At some point in the compression sufficient fissionable material will be accumulated to become critical, the plasma will be rapidly heated and a reverse shock will take place. (*more*)

* In general a conductor moving in a magnetic field feels a force tending to push it in the direction of lower field. This happens because eddy currents are induced in the conductor that generate a magnetic field which cancels out the external magnetic field within the conductor volume. (Magnetic field lines cannot penetrate into an ideal conductor.) The interaction of these eddy currents with the original magnetic field behaves exactly as if the magnetic field exerted a pressure $H^2/8\pi$ dynes/cm^2.

The cycle therefore consists of a series of oscillating shock waves produced by the alternate criticality of either end of a cylindrical system. A magnetic coil oscillating with a condenser removes some of the kinetic energy of the gas flow behind the shock. The coupling between the magnetic field and the gas comes from the electrical conductivity of the extremely hot ionized gas.

Design-Parameter Estimates

To determine the engineering feasibility of such a device estimates are needed for the following design parameters: the operating temperatures of the gas and the container walls, the physical dimensions of the reactor cylinder, the density of the gas, the total power output, the strength of the magnetic field, the frequency of the critical oscillations, and the over-all power-plant efficiency. The physics of the situation is obviously quite complicated and involves these quantities in relationships that are not easy to describe mathematically. In fact a careful attempt to determine the physical variables of the system would be a very difficult task and would require supporting experimental investigation.

One can, however, start with a few reasonable assumptions and use "order-of-magnitude" arguments to obtain rough estimates of the interesting design parameters. This kind of approach produced the results shown in the table. The physical arguments used to obtain these numbers will be outlined later.

In deriving these estimates the following things were assumed:

- The gas is uranium metal (boiling point 3,900° K).
- The gas is surrounded by a cylindrical graphite container.
- The maximum heat flux through the graphite is 1 kw/cm², and the inside wall temperature is 3,500° K.
- The graphite is itself surrounded by a D_2O blanket that provides neutron moderation and reflection and removes heat from the graphite.
- The mechanical to electrical energy conversion is 70% efficient (does not include thermodynamic efficiency).

Although some of the numbers quoted in the table are extreme, none appears to be completely beyond reality. Certainly the construction of a fission plasma device seems feasible enough to deserve more thorough investigation.

Pros and Cons

Compared with a conventional reactor a plasma reactor would have the following advantages:

1. Since it is a low-pressure system and the supporting structure is at low temperature, the structural hazards are reduced.
2. The fissionable material is the working gas so that no heat exchangers need handle the radioactive material.
3. No prime turbine is needed although the same quantity of rotating electrical equipment will be used.
4. Because the fissionable material is at extremely low density, the prompt-fission multiplication rate is low enough to allow mechanical control of power excursions. In addition it can be shown that the criticality achieved by shock compression decreases once the radiation rate increases above the operating condition so that the reactivity has a negative temperature coefficient above the normal operating temperature.
5. Finally there is the distinct possibility that the thermodynamic efficiency can be raised up to 50%. This would be considerably higher than the efficiency of any conventional system.

The disadvantages are:

1. If U metal is used as the gas the wall temperature of the reactor must be very high, ~3,500° K. The use of carbon in this condition has not yet been sufficiently studied to determine feasibility, but other programs may develop the technology required. The discovery of a gaseous U compound that is stable at high temperatures would help this problem.
2. The minimum theoretical size is quite large. This makes a research effort difficult, but the size is not beyond that of modern large power plants.

The Basic Idea behind the Direct Production of Electricity

That electrical power is generated as a result of the interaction of the moving plasma with the coil-condenser oscillation can be understood in terms of the forced oscillation of a tuned electrical circuit. In this case the coil and condenser in parallel form a tuned resonant tank circuit. (See figure.) The oscillation is forced by the interaction of the induced eddy currents in the conducting plasma with the currents in the main coil. The eddy currents in the moving plasma are induced because the plasma is a conductor moving in a magnetic field. Since the induced current in the plasma is in such a direction as to give a net retarding force on the plasma, the electrical oscillations in the coil-condenser tank circuit are "forced" to a greater amplitude at the expense of the mechanical energy of the plasma motion. The consequent conversion of mechanical energy to electrical energy of resonant oscillation is the basis of electrical power generation.

Estimating the Parameters

The physical arguments used to derive the numbers shown in the table are intended to give order-of-magnitude design estimates rather than precise values.

Operating temperature. There is a good chance that UF_6 will prove to be stable enough at high temperatures to be used as the gas. However, we will derive the operating temperature assuming that the gas is uranium metal. The minimum ambient temperature will then be the boiling point of the metal or 3,900° K. The maximum temperature is determined by the rate of thermal radiation from the gas to the walls. An approximate estimate is that the gas will behave as a black body with an emissivity of 10% to 20%.* From an engineering standpoint the maximum heat flux that a carbon wall might take is 10^3 watts/cm². Assuming this much power is radiated to the wall, the black-body temperature for 10% emissivity is then determined by

$$\text{Radiated power} = 5.7 \times 10^{-12}\theta^4 \times 0.1 = 10^3 \text{ w/cm}^2$$

or

$$\theta_{max} = 6{,}500° \text{ K } (0.56 \text{ ev})$$

The carbon wall temperature can be about one half of this and yet maintain uranium-metal vapor at 1-atm pressure.

Plasma conductivity. The electrical conductivity of the heated gas is one of the factors that determine the mini-

* Even with a good neutron reflector the fission mean free path for neutrons in the gas will not be more than 20 times the width of the active region. If, as will be shown later, the fractional ionization is a few percent or greater, then the optical absorption cross section of the gas will be of the order of 10^4 times the thermal-fission cross section. The mean free path for photons will then be much shorter than the thickness of the gas so that the conditions for black-body radiation are satisfied. The fractional emissivity of 10% is due to the temperature gradient near the gas surface.

An alternative approach is to calculate the continuum radiation per unit volume of gas assuming the gas is transparent. One finds that this gives a much greater total energy flux than that obtained from the black-body calculation. Since the radiation rate can never be greater than the black-body limit, the black-body calculation is then justified.

mum feasible radius for the cylinder. If the fractional ionization is higher than 10^{-3}, the properties of the ionized gas (the plasma) rather than those of the neutral gas determine the conductivity (*1*, *2*). The fractional ionization of the uranium gas at a temperature of 0.56 ev can be obtained by solving the Saha equilibrium equation for a plasma. If x is the fractional ionization

$$\log\left(\frac{x^2}{1-x^2}p\right) = -6.18 + \log\frac{g_2}{g_1} + \frac{5}{2}\log\theta - \frac{5{,}040V}{\theta}$$

where V = ionization potential of uranium in electron volts = 4.0 ev

$\frac{g_1}{g_2}$ = ratio of statistical weights of ionized state versus neutral state = ½

p = pressure in atmospheres

θ = temperature in ° K = 6,500° K

Putting in the numbers

$$\frac{x^2}{1-x^2}p = 3.3$$

A pressure of 1 atm (which is a likely pressure) gives a fractional ionization of 0.87. Since this is large compared with 10^{-3} the conductivity can be estimated by assuming the gas has the properties of a plasma.

Spitzer (*2*) gives the electrical conductivity, Ω, of a plasma in a magnetic-field-free region*

$$\Omega = \frac{\theta^{3/2}}{2\times10^4}\ \text{ohm}^{-1}\,\text{cm}^{-1}$$

If θ = 6,500° K then $\Omega = 26\ \text{ohm}^{-1}\,\text{cm}^{-1}$.

The conductivity is related to the cylinder radius in that both influence the electrical efficiency of the direct-conversion process. Since the conductivity of the plasma is not infinite (not a perfect conductor), resistive losses will accompany the eddy currents set up in the plasma when it enters the magnetic field. These losses represent irreversible energy losses and therefore determine the efficiency of the conversion process.

The magnitude of the losses is related to the distance the magnetic field penetrates into the conductor. This distance is known as the "electrical skin depth." (For infinite conductivity the skin depth is zero; for finite conductivity the skin depth increases with decreasing conductivity.) The electrical efficiency is roughly the ratio of the area of the magnetic-field penetration to the total area of the plasma corrected for the fact that the magnetic field falls off as it penetrates into the plasma. For high electrical efficiency the skin depth must be small compared with the radius of the plasma.

Besides conductivity the skin depth also depends on how fast the plasma travels through the magnetic field—i.e., how much time is available for the magnetic field to diffuse into the plasma. A rough estimate of this time would be the radius of the cylinder divided by the plasma velocity through the coil.

The expression for skin depth is

$$\delta = \frac{10^9 t^{1/2}}{8\pi\Omega} = 10^9(r/u)^{1/2}/8\pi\Omega = 1.2\times10^3(r/u)^{1/2}\ \text{cm}$$

where u = plasma velocity in cm/sec

r = radius cylinder in cm

t = time in seconds

Order-of-Magnitude Design Figures for a Plasma Reactor

Cylinder dimensions	
Radius*	13 ft
Length	150 ft
Maximum operating temperatures	
Gas temperature	6,500° K
Graphite wall temperature	3,500° K
Gas density†	5×10^{17} atoms/cm³
Gas pressure	~1 atm
Total electrical power generated	4.8×10^5 kw
Magnetic-field strength	3,170 gauss
Velocity of expanding gas	1.6×10^5 cm/sec
Oscillation frequency	about 20 cycles/sec
Thermodynamic efficiency	30%
Over-all power-plant efficiency	20%

* Minimum theoretical value.

† Air density at STP is 5×10^{19} atoms/cm³

If we assume an electrical efficiency of 70% then the skin depth should be less than about 15% of the radius, or $\delta = 0.15r$. We have finally

$$r = 8\times10^3\,(r/u)^{1/2}\ \text{cm}$$

or

$$r = \frac{6.4\times10^7}{u}\ \text{cm}$$

Plasma velocity. The last equation shows that the dimension of the machine is smaller for a higher plasma velocity. One is tempted therefore to dilute the high molecular weight of uranium with an inert carrier gas of low molecular weight (e.g., helium) to increase the gas velocity. However, to have sufficient time for neutron multiplication, the shock speed must be less than thermal-neutron velocity (2.2×10^5 cm/sec). This restricts the addition of low-molecular-weight diluents.

If the gas density in the critical end of the reactor is at least twice the average density (as one would expect from the prior compression of the previous shock), then for a large, sudden change in temperature of the critical driving gas, the plasma speed should be approximately twice* the speed of sound in the cold gas.

The speed of sound in the driving gas is

$$C_D = 1.8\times10^5\left(\frac{1}{M_{eff}}\frac{\theta}{278}\right)^{1/2}\ \text{cm/sec}$$

M_{eff} = effective molecular weight

θ = temperature in degrees K

Since the uranium is largely ionized the effective molecular weight is

$$M_{eff} = \tfrac{238}{2} = 118$$

and

$$C_D = 8.2\times10^4\ \text{cm/sec}$$

The estimated velocity of the plasma is then

$$u = 2C_D = 1.64\times10^5\ \text{cm/sec}$$

For 70% electrical efficiency the minimum radius of the cylinder turns out to be

$$r = \frac{6.4\times10^7}{u} = 400\ \text{cm}$$

Gas density. The density of the

* When the shock, or disk of ionized gas, enters the magnetic-field coil, the induced current is normal to the magnetic field so that one would suppose that the electrical conductivity normal to a strong magnetic field would apply. This, however, is not the case because the electron scattering mean free path will be much shorter than the cyclotron radius in the magnetic field, so that the field-free conductivity applies.

* In fact the limiting velocity for infinite pressure ratio is $u = \frac{2C_D}{\gamma-1}$ or $u = 3C_D$ since $\gamma = \frac{5}{3}$. This holds because the shock is driven by an adiabatic expansion of the driving gas.

fissionable gas in the cylinder is a crucial design parameter. The density must be adjusted so that the fission energy is released in a time short enough to form a shock wave at the critical end. This implies that the energy be generated within the time the fissionable gas takes to flow into and subsequently flow out of the critical end. The time for energy generation (t_E) will be of the order of twice the time for sound to travel the diameter of the cylinder, or $t_E \cong 2D/u = 10^{-2}$ sec.

There are two possible neutronic modes of operation that can give rapid heating of the fissionable gas. The most obvious is that the density of the U^{235} gas be high enough so that when it is compressed in one end of the cylinder about two neutron-multiplication generations take place within 10^{-2} sec (i.e., the reciprocal period $\alpha = 200$). To achieve such a fast period the peak reactivity must be 3 to 6 times critical. On the other hand, after the shock leaves, the neutron flux must decay by a factor of 10 before the shock returns. Otherwise the average neutron flux will be continuously increasing. However, the gas density falls by a factor of only 5 or 6 after the shock leaves. With such a high peak reactivity this is not enough decrease in density to give sufficient decay of the neutron flux within the shock-return time. The dual conditions of rapid heating and constant average neutron flux cannot be achieved by this mode of neutronic operation.

The second possible mode of neutronic operation is to arrange for the neutron flux to stay high and relatively constant in time within each reflecting end. In the region of the coil between the end, the neutron flux can be greatly reduced through leakage and absorption in the wall. When the bulk of the U^{235} gas is in either end, the high but constant neutron flux heats it, rapidly creating a shock. The subsequent expansion causes flow of the U^{235} gas out of this end but will not drag the neutrons with it. Since the neutron scattering cross section in U^{235} is a very small fraction of the total reaction cross section, the U^{235} gas leaves, but the neutrons stay behind. The low-density U^{235} gas left behind will of course see the same heat input per unit mass (the neutron flux is constant), but the temperature should fall rapidly because of the large change in radiation opacity. Consequently the return shock sees low-temperature low-density gas that can be again compressed.

It is not entirely clear that the constant-in-time neutron mode will support an oscillating shock; however, a slight oscillation of the neutron flux is all that is needed to ensure a shock behavior. Therefore a combination of the two neutronic modes is proposed. The oscillation of the neutron flux should be approximately 1.5 to 1 (i.e., $\alpha = 40$), which is low enough so that a steady power level can be achieved and also an attractively low-density U^{235} gas can be used.

The next step is to find what gas density will give an $\alpha = 40$ in the compression phase of the cycle.

First we will show that the neutron spectrum is thermal. The construction design envisioned (see figure) is that of a cylindrical tank 8 meters in diameter whose walls are lined with graphite surrounded by a thick blanket of D_2O moderator. The thickness of the graphite lining must be adjusted to maintain a temperature difference of 3,200° K for a maximum heat input of 1 kw/cm². The high-temperature thermal conductivity of graphite is ~0.1 cal/cm²/° K/sec. Therefore, the thickness of graphite becomes

$$0.1 \times 3{,}200/D = 1{,}000/4.18$$
$$D = 1.3 \text{ cm}$$

Since a thermal-neutron mean free path in graphite is 2 cm the neutrons that are returned by the D_2O blanket will not come into thermal equilibrium with the graphite. Instead they will enter the reacting system in an essentially room-temperature thermal (0.025-ev) distribution. (The high temperature of the uranium itself does not affect the fission cross section because the uranium velocity distribution is still slow relative to the thermal-neutron velocity.)

If time taken for both the slowing down of the fission neutrons and the reflection of the thermal neutrons is neglected, a simple estimate of the U^{235} gas density can be made. For a sphere 4 meters in radius surrounded by an infinite D_2O moderator, the return probability of a fission neutron is $P_r = 0.75$. The additional loss due to thermal-neutron absorption and loss in the middle region of the cylinder can be approximated by a factor $P_a = 0.9$.

Let ν = neutrons per fission of $U^{235} = 2.5$ and

$$\eta = \sigma_f/\sigma_a\nu = 2.5/1.18 = 2.1$$

To obtain an α of 40 a thermal neutron must travel an effective multiplication mean free path in a time $1/\alpha$ seconds. The multiplication mean free path is the absorption mean free path increased by the factor

$$\frac{1}{P_a(P_r\eta - 1)}$$

Therefore

$$\frac{v_n}{\alpha} = \frac{1}{\rho\sigma_a P_a(P_r\eta - 1)}$$

v_n = velocity of thermal neutron = 2.2×10^5 cm/sec

$\alpha = 40$

ρ = density of U^{235} in particles/cm³

σ_a = 687 barns = 6.87×10^{-22} cm²

Then the required density of fissionable gas is

$$\rho = 5.1 \times 10^{17} \text{ } U^{235}/\text{cm}^3$$

With this density the absorption mean free path is $1/\rho\sigma_a = 2.8 \times 10^3$ cm. Since the cylinder diameter is only 800 cm a thermal neutron will make on the average five traversals of the reacting volume before it is absorbed in the gas. The albedo of the reflector for thermal neutrons is approximately 98% (i.e., permitting 50 reflections before absorption in the moderator). The neutron economy is then good enough to afford considerable thermal absorption near the midregion of the coil, thus giving the required reduction in neutron density between the coils.

Cylinder length. The length of the cylinder must be great enough so that

Proposed Experimental Program

The design uncertainty most in need of experimental investigation is the effective electrical conductivity of the plasma. This has been estimated assuming an electron velocity distribution very close to thermal. High current density, large inelastic-collision cross section and large nuclear ionization are all effects that tend to cause electron velocity distribution different from thermal. (Fortunately these effects are in the direction of higher conductivity or smaller minimum size for the reactor.)

Unfortunately an experimental investigation must be made on equipment close to the actual size, but this is not so big a problem as might be imagined. A shock tube, 1 meter in diameter, 6 meters long, operating at 1 atm maximum pressure with a magnetic field of 5,000 gauss at the midpoint would give complete answers not only on electrical conductivity but on electrical cycle efficiency, radiation cooling and thermal conductivity as well.

the shock has a sufficient length in which to form and also long enough so that the neutron absorption at the coil region does not reduce the reactivity. A total length six times the diameter gives a length of three diameters at either end before the shock reaches the coil and also places the coil far enough from the ends so that the fractional neutron flux reaching the coil is small.

Power output. To obtain a crude estimate of the power output assume that one tenth of the time the shock is doing work against the magnetic field. Then

$$W = \text{pressure} \times \text{area} \times \text{velocity} = 6 \times 10^5 \times (400)^2\pi \times 1.6 \times 10^5 \times \tfrac{1}{10}$$

or

$$W = 4.8 \times 10^5 \text{ kw}$$

This is an acceptable power rating but is rather large in view of the fact that the design is predicated on a minimum size.

Gas cooling rate. To maintain the oscillations the shocked gas must cool by roughly a factor of one half during the time the residual shock takes to travel from the coil to the sofar noncritical end. (The cooling will take place by radiation since thermal conductivity is negligible.) The magnetic field must reduce the shock velocity by roughly one-half so that the time for cooling is

$$t_c = 6 \times 400 \times 2/(1.6 \times 10^5) = 3 \times 10^{-2} \text{ sec}$$

The shocked gas disk will be about one radius thick so that the area and volume are

$$\text{Area} = 4\pi r^2 = 2 \times 10^6 \text{ cm}^2$$
$$\text{Vol} = \pi r^3 = 2 \times 10^8 \text{ cm}^3$$

The radiated energy at 10^2 w/cm^2 in 3×10^{-2} sec is

$$W = 2 \times 10^6 \times 10^2 \times 3 \times 10^{-2} = 6 \times 10^7 \text{ joules}$$

About one half of the work done by the driving pressure will appear as kinetic energy of the gas flow and one half as heat content. The heat content of the shocked gas is therefore 0.04 joule/cm^3, or 8×10^6 joules total. Since this is small compared with the amount that could be radiated, as calculated above, we conclude that the gas will cool rapidly enough to meet the requirements of the design.

It is evident that the radiation rate may not be optimum at this value. The cooling rate can be adjusted by:

1. Operating at a slightly different temperature.
2. Using a different radius and density.
3. Changing the length with other parameters fixed.

Magnetic-field strength. The magnetic field must be strong enough to reduce the shock speed by about one half. (Since the kinetic energy is proportional to the velocity squared, this removes 75% of the kinetic energy of fluid flow.) The value of the magnetic field must be such as to give a pressure roughly equal to the driving pressure of 0.4 atm, or

$$4 \times 10^5 = H^2/8\pi$$

or

$$H = 3{,}170 \text{ gauss}$$

External-circuit behavior. That the plasma actually transfers energy to the external resonant circuit can be shown by applying ordinary circuit theory. The coil in the figure is shown schematically in resonance with a capacitor bank. In practice, the capacitor bank would be a synchronous motor, but the principal of power generation is the same.

The oscillating shock wave can be thought of as a moving conductor that periodically changes the inductance of the coil. The capacitor voltage is

$$V = \frac{d}{dt}(LI)$$

where both L (inductance) and I (current) are periodic functions of the time. For a capacitance C

$$V = \frac{1}{C}\int I dt$$

or

$$\frac{dV}{dt} = \frac{I}{C}$$

Differentiating above and substituting

$$\frac{I}{C} = \frac{d^2}{dt^2}(LI)$$

If we let $x = LI$, then

$$\frac{d^2x}{dt^2} - \frac{x}{LC} = 0$$

Since the parameter L is a periodic function of time, the above equation is the Hill-Mathieu type, which, by Floquet's theorem, has the following solution:

$$x = a_1 e^{st} p(t) + a_2 e^{-st} p(-t)$$

where a_1 and a_2 are constant coefficients and $p(t)$ is a periodic function in time. The coefficient of the exponential is not determined, but the positive exponent term describes the case in which power is fed into the coil-condenser system. For this solution x becomes a periodic, exponentially increasing term. Since $x = LI$ and L is a bounded periodic function, then I is an unbounded periodic function. In practice the oscillations of I increase until the power dissipated into an external load becomes equal to the power input.

System efficiency. The electrical efficiency of the cycle is entirely determined by the resistive diffusion of the magnetic field into the plasma. The electric losses in the rest of the system should be negligible because large-size conductors can be used (i.e., the Q of the coil-condenser system can be made large). The diffusion loss in the plasma per cycle is the ratio of resistive loss to the mechanical work done. This is roughly the ratio of the area of flux penetration to total area of the plasma corrected for the fact that the magnetic field that diffuses at the outside radius is stronger than the average field. For this reason a 15%-of-radius field penetration will probably give a 70% efficient electrical cycle.

The thermodynamic efficiency can be approximated in the strong-shock limit by observing that one half the energy of expansion goes into thermal shock heating (irreversible) and one half into kinetic energy of fluid motion. If the magnetic field slows up the fluid flow by one half, it removes 75% of the kinetic energy, or 37% of the total energy of expansion. Radiation cooling will account for an additional 20% loss so that a probable thermodynamic efficiency of 30% seems likely. This results in over-all plant efficiency of 20%. The electrical efficiency can be improved by going to a larger size. The thermodynamic efficiency can be improved slightly by changing the effective γ of the gas with diluents.

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* * *

This work was supported by the U. S. Atomic Energy Commission. S. A. Colgate is primarily responsible for the electrodynamic cycle; L. Aamodt has calculated the neutronics of the gaseous reactor in much greater detail than appears here. William Ogle of Los Alamos contributed substantially to the early discussions.

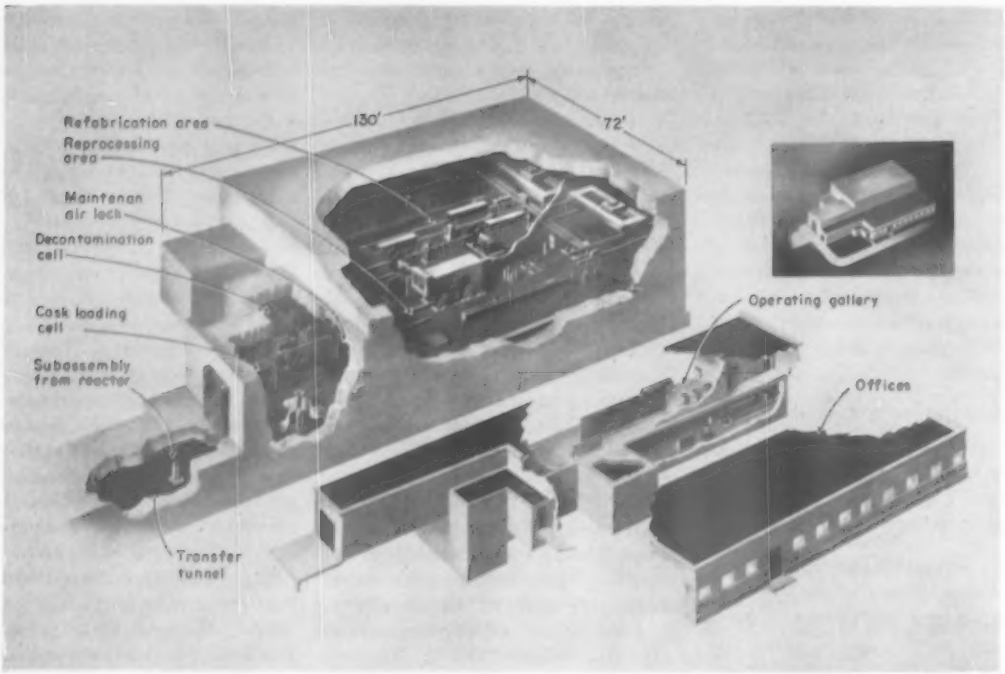

FIG. 1. Artist's concept of pyrometallurgy plant for reprocessing spent fuel from fast breeder reactor. Refabrication and reprocessing areas are at top with transfer tunnel from reactor at left. In center is plant operating gallery. At bottom are offices

DESIGN AND COST ESTIMATE FOR A

Pyrometallurgical Reprocessing Plant

A pyrometallurgical reprocessing plant, using the oxide-slagging method, can handle 18,000 kg/yr of enriched uranium alloy at $79/kg. The highly radioactive product requires remote refabrication. Certain modifications should lead to lower costs

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PYROMETALLURGY may be the means for economically reprocessing the enriched fuel of fast breeder reactors. The processing-plant concept presented here (Fig. 1) was developed as an adjunct to the Enrico Fermi nuclear power plant.

Pyrometallurgical (PM) processes treat fuel in the molten metallic state, using inorganic extraction or reaction media to effect the desired separations. Since inorganic materials are highly stable under irradiation, the decay time of three to four months required before contacting with radiation-sensitive organic solvents can be reduced to a few days, drastically reducing inventory charges. PM processes also allow

handling fuel in larger batches since aqueous moderators are avoided.

The major disadvantage of most PM processes is their incomplete removal of fission products from the reprocessed fuel. Fortunately, this factor is not too important for fast reactors because of their high tolerance for fission-product buildup in the fuel. However, the residual radioactivity is so intense that refabrication must be done remotely. There is no remote fabrication being carried out today at such high activity levels, and it is anticipated that this operation will be costly. Since PM processing necessitates the use of remote fabrication, the cost of both operations must be known to determine over-all fuel-cycle economics. However, only the processing is treated in detail here.

The Story Behind This Design

Atomic Power Development Associates (APDA) has been working for the past few years on the design and development of the Enrico Fermi fast breeder reactor, which is expected to begin operation in late 1960.

Early in the study, development of an efficient fuel-reprocessing cycle was recognized as an important cost factor. This is expecially true in fast reactors because they are characterized by having a high throughput of moderately enriched fuel. This affects conventional aqueous reprocessing costs in two ways:

1. The normal decay time of 3–4 months requires that large amounts of valuable fuel be tied up in storage with a resultant high inventory charge.

2. Low-capacity plants with high costs must be used for enriched fuels because aqueous solutions are well moderated and small equipment must be used to prevent the attainment of criticality.

As part of the basis for fuel- and power-cost estimates, APDA sponsored several refabrication* and fuel-reprocessing studies. The latter were short-cooled-aqueous, fluoride-volatility and pyrometallurgical (PM) processes. The PM study, which was conducted by Vitro Corp., is the subject of this article.

The Vitro PM study was intended to give APDA a picture of what such a plant, with its high activity, remote handling, and shielding, may look like. It is possible that the final plant will utilize a different pyrometallurgical process but one that requires similar handling.

* The results of the refabrication study conducted by Vitro Corp. were presented at the March 1957 Nuclear Engineering and Science Conference.

Design Basis

The following items present the basis for the design of the pyrometallurgy plant:

Reference process	Oxide slagging
Subassemblies to be processed	Core segments consisting of 18 fuel plates, 30.5 × 2.48 × 0.040 in.
Plant capacity	20 subassemblies/week, or 18,000 kg/yr of fuel alloy
Decay time	Two days after removal from reactor
Plant location	600 ft from reactor
Decanning	Subassemblies disassembled in PM plant under molten sodium

Oxide Slagging

The oxide slagging process, which was developed at Argonne National Laboratory and Atomics International, was assumed in this study.

Figure 2 shows a slagging crucible. The distribution shown is only approximate since most of the fission products are not completely transferred to any one phase. With the use of actual distribution coefficients, the concentration buildup of the various fission products as a function of the number of cycles of irradiation and reprocessing was determined and is shown in Fig. 3.

The concentrations of most of the fission products level out after just a few cycles to rather low values. The concentrations of the noble-metal fission products like ruthenium and molybdenum, however, build up linearly during 20 cycles when a 5% fuel purge is assumed to limit further buildup. This metal purge is sent to an aqueous reprocessing plant for fuel recovery and complete removal of all fission products.

The "equilibrium" alloy thus obtained would have approximately 1.7 wt % Pu, 1.6 wt % Ru, 2.3 wt % Mo and 94.4 wt % U.

Very little is known about the effects of Pu and Ru on irradiation stability and fabricability of uranium alloys. Molybdenum, however, has been used as an alloying agent with good results in concentrations of about 9%. It was, therefore, assumed that the equilibrium alloy would be satisfactory for refabrication and reirradiation.

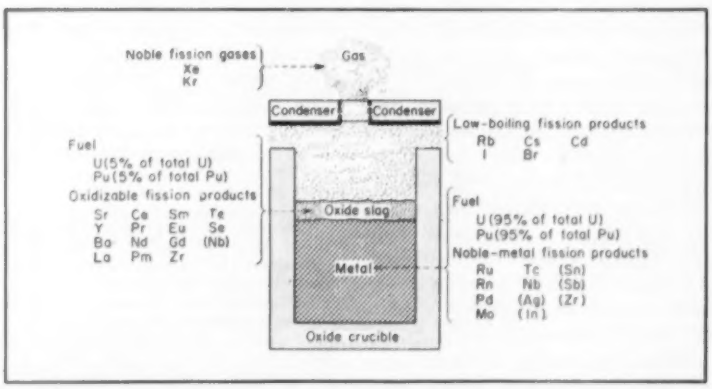


FIG. 2. Oxide-slagging process (parentheses indicate negligible concentrations)

Plant Facilities

The PM plant is connected to the reactor shipping facility by a 600-ft tunnel and contains process and fabrication cells, air locks (including maintenance, decontamination and cask-loading cells), a "cold" equipment gallery, an operating gallery, "hot" and "cold" laboratories and an office area. The plant flow sheet is shown in Fig. 4.

Building. The building is constructed of reinforced concrete throughout with expansion joints offset to maintain necessary shielding. Heavy remotely controlled shielding doors are of high-density, barytes-aggregate concrete. The roof is surfaced with a mastic coating.

The reprocessing and refabrication cell is a monolithic concrete structure

shielded by 6 ft of concrete on all four sides and overhead. The floor is 1 ft thick, and a 1-ft inside wall divides the reprocessing from the fabrication area. An argon atmosphere is constantly maintained in the cell and in the maintenance air lock, adjacent to the cell. The reprocessing cell is completely lined with steel, with a 1-in. space under positive argon pressure maintained between the steel and concrete. The only connections between the cell and outside facilities, other than piping, electrical and instruments, are the floor opening for transferring fuel elements between the tunnel and the cell (this port has a sealing cover and facilities for purging), the door between the cell and air lock, and a pneumatic tube for transferring samples from the cell to the hot laboratory.

Cell pressure will be maintained by the addition of fresh argon. Ambient cell temperature will be maintained at ~200° F by recirculating cell argon through a cooling system consisting of two blowers, a filter, cooler and N_2-removal unit. A monitored cell-purge stream is taken off just after the filter and vented to the stack fan, which provides suction on the cell.

The ventilated concrete tunnel permits shielded delivery of irradiated elements from the reactor as well as transfer of small items between the decontamination and the process cell. A system of three air locks permits movement of equipment, accessories, blankets, element segments and other miscellaneous items that require transfer to or from the cell.

Operations performed in the cell, tunnel and air locks are directed from an operating gallery, with major process operations controlled from a central instrument panel. An SWP (special work permit) area is below the operating gallery. The principal equipment housed in the SWP area is the pumps and surge tanks for the primary (NaK) and the secondary (water) coolant systems.

A conventional "hot cave" adjacent to the reprocessing facility has been provided to analyze the fuel-element samples from the refabrication plant. The major piece of equipment is a double-diffraction spectrograph or densitometer for making qualitative and quantitative analyses of the uranium isotopes and fission products. Facilities for routine laboratory work have been provided in a cold laboratory.

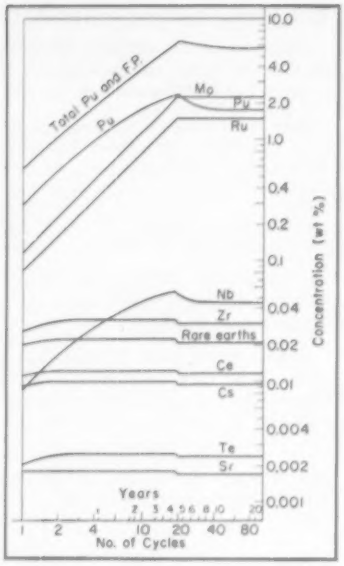


FIG. 3. Pu and fission-product buildup. Fission products with similar chemical and/or physical properties are grouped together. Basis for graph: 1% total burnup per cycle, 5% metal purge to recovery plant every cycle after the 20th

Instrumentation and control. The instrument systems and components have been kept as simple as possible to conform with the criteria of flexibility, reliability, safety, remote operation and economy and have been selected from standard commercially available types.

Process operations are controlled and monitored from a control panel located in the operating gallery.

Beta- and gamma-radiation monitoring is provided on process lines that exit from the cell. Alpha monitoring by continuous air sampling is provided for all SWP areas. The instrumentation and controls for the furnaces and their associated NaK coolant systems are separate and identical to each other.

Electrical system. Because of the inaccessible nature of this plant, an electrical system with maximum reliability and minimum maintenance was used. Motors are of the totally enclosed, fan-cooled type with Class H insulation and remote starting and control equipment. To minimize radiation damage on electrical insulation, all wiring in the "hot" area is metallic-sheathed cable insulated with silicone-impregnated mica or mineral insulation.

Motors and heaters in the cell area are wired by means of "connectors" and jumpers, which can be removed and installed by the manipulator.

The furnace work coils, as well as the "pouring coil," consist of two identical tubular coils connected in parallel electrically but in series hydraulically to prevent the coolant from short-circuiting the coil.

Cell viewing. About 85% of the cell is visible from the three shielding windows. This coverage is postulated on the use of built-up glass windows using 3.3 density, nonbrowning, cerium-stabilized glass 40 in. thick, together with 8 in. of 6.2-density lead glass on the outside.

Cell operations are monitored by periscopes or by television cameras inside the cell with receivers located on movable consoles in the operating gallery.

NaK coolant systems. NaK (22 wt % sodium–78 wt % potassium alloy) is a liquid metal at room temperature (its melting point is 66° F) and has a reasonably low vapor pressure at the operating temperatures used in this facility. Besides having good thermal properties, NaK is easily pumped, not corrosive, relatively stable and, in general, compatible with nuclear materials.*

NaK cooling systems have been employed in this facility as an intermediate means of heat exchange between cooling water and heat from (a) the three furnace induction coils, (b) fission-product decay in the off-gas systems, and (c) the heat gain of the argon cell atmosphere.

Special shielding. The element storage rack and the slagging furnace have gamma activities 100 times greater than other radiation sources in the cell. Therefore, to reduce damage to materials in the cell, these areas have local steel shielding to reduce the level to 10^5–10^6 r/wk in most of the cell area. This minimizes the special shielding required for such materials as gaskets, electric motors, oil bearings, etc.†

Movement of materials. Movement of all materials in the processing cell, not handled by an integral part of the processing line, is effected by either

* Hydrogenous materials have been excluded from this facility because of their nuclear moderating properties and chemical reactivity with alkali metals.

† There is some question as to the exact amount of gamma flux required to cause these various types of equipment to become inoperative. However, the range is between 10^7 rads for the threshold damage to motors and 10^9 rads for 50% damage to neoprene-coated wire.

This is the material balance at various points . . .

Basis: 72 lb Irradiated Fuel Alloy (Two Subassemblies)

Flow sheet points	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	⑮
Enriched uranium	67.06		67.06	3.35	63.71	7.81	71.52	67.95	3.57						
Noble fission gases	0.11	0.11								0.11	0.11				
Low-boiling F.P.	0.15	0.15										1.00	1.15	0.15	
Oxidizable F.P.	0.38		0.38	0.34	0.04		0.04	0.04							
Noble-metal F.P.	2.93		2.93		2.93		2.93	2.78	0.15						
Plutonium	1.37		1.37	0.07	1.30		1.30	1.23	0.07						
Sodium												10.00	10.00	1.30	1.30
Total	72.00	0.26	71.74	3.76	67.98	7.81	75.79	72.00	3.79	0.11	0.11	11.00	11.15	1.45	1.30

. . . in the pyrometallurgical reprocessing plant

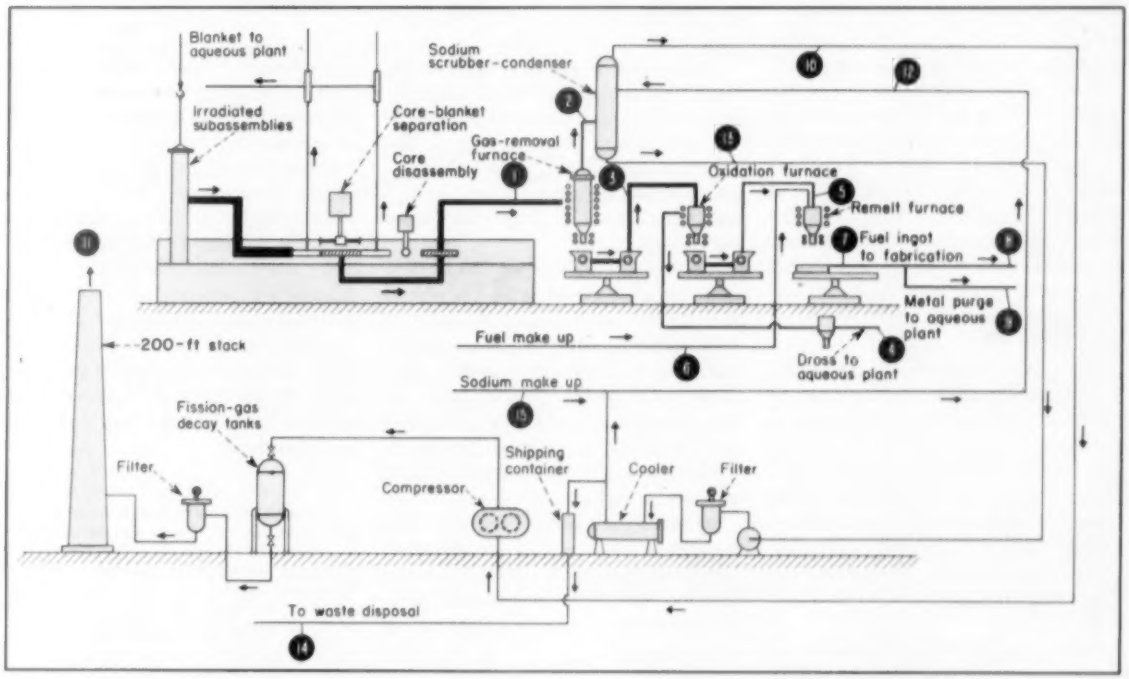


FIG. 4. Pyrometallurgical reprocessing flowsheet. Irradiated subassemblies are transferred from reactor in containers filled with sodium to remove fission-product decay heat. Under sodium, subassembly is withdrawn from horizontal pot and disassembled. Fuel plates are transferred in perforated basket ① to gas-removal furnace (furnace consists of tantalum crucible with bottom outlet and cover that is sealed by argon pressure). Plates are melted and sodium and low-boiling fission products volatilized by induction heating coil.

Off-gases pass ② to scrubber-condenser through electrically heated vent system. Recirculated sodium ⑫ at 400° F dissolves low-boiling fission products; sodium is recycled ⑬ through filter and cooler; portion of sodium is purged periodically ⑭ and replaced from makeup ⑮. Noble fission gases, which are not condensed, are compressed ⑩ into 12 cylinders for 12-week decay and periodic discharge to atmosphere ⑪.

Metal discharged from gas-removal furnace ① is held in oxidation furnace at 2,400° F for 4 hr. Furnace consists of oxide-coated (e.g., alumina) graphite crucible; lining forms slag on melt surface with oxidizable nonvolatile fission products. After bottom-pouring processed metal into ladle, slag adheres to crucible walls as film retaining about 5% of metal. One crucible treats about 10 batches; crucible containing accumulated dross is shipped ④ to aqueous processing facilities for uranium recovery.

Processed metal from oxidation furnace is transferred ⑤ to remelt furnace where it is mixed with enriched-uranium makeup ⑥. Reconstituted metal is cast into ingots ⑦ and transferred ⑧ for remote refabrication. Remelt furnace is also available for remelting recycled fabrication scrap.

Since noble-metal fission products are not removed in PM process, 5% of reprocessed metal is sent ⑨ to aqueous reprocessing for removal of these contaminants.

TABLE 1—Estimated PM-Plant Construction Costs

Site preparation	$ 14,000
Site improvements	76,000
Tunnel	648,000
Reprocessing building	408,000
Equipment	1,417,000
Piping, electrical, heating, ventilating, etc.	456,000
Stack	84,000
Air-compressor building	6,000
Maintenance shop	126,000
Purging of cell with argon	42,000
Total construction cost*	$3,277,000

* Including fringe benefits for labor, general contractor's overhead and profit, spares, contingency, design and engineering, etc.

crane or manipulator. In addition, a monorail hoist is provided for routine operations performed in the air locks. Transfer of large equipment out of the process cell is through the maintenance air lock. Subassemblies, blanket segments, scrap steel, used crucibles and other small items are transferred through the port in the floor of the process cell connecting with the tunnel. Material is moved through the tunnel by means of an electrical transfer cart.

Cost Estimate

The cost estimate for the PM plant was prepared from vendors' quotes on standard equipment and estimates of nonstandard items such as the decanning machine, transfer cart and induction furnaces. A detailed cost breakdown was made of building structure; piping; electrical, heating, and ventilating systems; instrumentation; etc. The estimate was made in January, 1956.

Table 1 shows the estimated construction costs for the PM plant. Note that the tunnel cost alone is $648,000. If the PM plant can be located adjacent to the reactor building, this amount can be reduced appreciably.

Approximately $1,150,000 of the $3,277,000 construction cost is for facilities used jointly by the reprocessing and refabrication facilities. The full cost of these shared facilities was included in the construction costs of the reprocessing plant to show the true estimated cost of the facilities described. However, part of the cost of the joint facilities should be allocated to the refabrication plant, which was estimated in a separate economic and design study.

Startup costs, which are not included, would provide for a 6-month operator training period plus a 6-month startup period and would add approximately $440,000 to the capital cost.

Table 2 shows estimated annual costs.

Room for Improvement

Many technical and economic questions must be answered before such a PM plant can be constructed.

The oxide-slagging process has been proved on a kilogram laboratory scale. No difficulty is anticipated in obtaining the desired fission-product removal. However, a number of related operations, e.g., sodium removal, volatile-fission-product collection, mechanical decanning, etc., have not been tested and require study to determine optimum methods of operation.

It was initially assumed that furnaces would be heated by induction. To avoid having hydrogenous materials in the process cell, NaK is used as the induction-coil coolant. Since the coolant systems are complex and costly, resistance heating might be more economical.

Another assumption was that two-shift operation would be used to reduce the capital investment. Because of high operating costs, the total annual costs might be less with one-shift operation and a slightly bigger plant. In this connection, preliminary estimates indicate that a substantial increase in capacity could be realized with a small increase in capital cost.

It was also assumed initially that blanket uranium could be processed more economically in off-site aqueous facilities and should not be handled in the PM plant. Recent studies indicate that blanket material might be processed by magnesium extraction in an enlarged PM facility without too great an increase in total costs.

Other problems that were not completely resolved by this study are crucible materials; dross-metal separation; magnitude of radioactive-decay heat; effect of radiation on materials; cell-gas purification; and safety considerations, such as disposal of wastes and type of cell liner for containment. These and several less important points must be studied and economic comparisons made before a final design can be determined.

TABLE 2—Estimated Annual Costs

Operating costs	
Direct cost	
Personnel	$280,000
Chemicals	75,000
Utilities	16,000
Materials	
Maintenance	50,000
Operating	22,000
	$443,000
Indirect cost*	$165,000
	$608,000
Fixed charges at 25% of total construction cost	819,000
Total annual costs	**$1,427,000**
Unit processing cost	$79/kg total U

* Labor, materials and overhead for administration, health physics, first aid, fire protection, etc., at 45% of direct cost without chemicals.

* * *

The authors wish to acknowledge the valuable assistance of personnel at Atomic Power Development Associates, Vitro Engineering Company and Argonne National Laboratory. They are also grateful to Atomic Power Development Associates, who sponsored this work, for permission to publish this paper.

Did you miss . . .

the EBWR foldout in the July Nucleonics? This was the first of a series of comprehensive descriptions of "reactors on the line." Here (facing page) is another on the APPR.

Coming in future issues are ORR, SRE, PWR.

All will be available as reprints for $0.25 each, in addition to being perforated in the magazine for easy removal.

Characteristics of APPR

Location:	Fort Belvoir, Virginia
Design concept:	Oak Ridge National Laboratory (ORNL)
Prime contractor:	ALCO Products, Incorporated
Architect-engineer:	Stone and Webster
Major equipment suppliers:	ALCO (pressure vessel, control rod drives, pressurizer, steam generator) Bethlehem Steel (containment shell) General Electric (steam turbine-generator) Lummus (condenser) Minneapolis-Honeywell (controls) ORNL (fuel elements, control rods)
On line:	April 15, 1957
Output—heat:	10,000 kw
—electrical:	2,005 kw

Component Design Data

Pressure vessel

Height:	13.5 ft
Inside diameter:	4 ft
Wall thickness:	2.75 in.
Composition:	carbon steel
Cladding	
—material:	stainless steel (304L)
—thickness:	0.250 in.
Design pressure:	1,600 psia
Test pressure:	2,400 psia

Core

Configuration:	modified rectangle
Size:	22.0 × 20.4 × 20.4 in.
Fuel:	22.5 kg U^{235}
Burnable poison:	21.1 gm B^{10}
Composition	
—H_2O:	79.22 vol %
—UO_2:	1.79 vol %
—B_4C:	0.04 vol %
—SS:	18.95 vol %

Control rods

Configuration:	square tube
Number:	7
Composition:	B_4C-Fe
Rod worth:	24.5 % $\Delta k/k$
Absorber length:	26.5 in.
Follower length:	24.8 in.
Follower material:	UO_2
Weight:	72 lb
Withdrawal rate:	3 in./min
Scram time:	0.53 sec

Control rod drives

Type:	rack and pinion
Number:	7
Power requirement:	440 v, 3φ
Motor rating:	$\frac{1}{8}$ hp, 1,175 rpm
Position indicator accuracy:	±0.0312

Fuel elements

Type:	plate
Number:	38
Enrichment:	93.2 %
Plates per element:	18
Meat dimensions:	22.0 × 2.50 × 0.02 in.
Meat composition	
—UO_2:	22.88 wt %
—B_4C:	0.12 wt %
—SS:	77.0 wt %
Cladding:	304L SS
Plate temp.—avg:	~490° F
—max:	550° F

Nuclear Design Data

Moderator

Type:	light water
Avg neutron energy:	< 0.17 ev
Thermal-neutron flux—avg:	2.7×10^{13} n/cm²/sec
—max:	1.0×10^{14} n/cm²/sec
Prompt-neutron lifetime:	2×10^{-5} sec
Eff. delayed-neutron fraction:	0.0073
Overall temp. coefficient:	-2.3×10^{-4}/° F
Pressure coefficient:	~3×10^{-6}/psi
Endurance:	13,140 FPH

Control requirement

Burnup compensation:	5.1 % $\Delta k/k$
Peak xenon override:	2.4 % $\Delta k/k$
Equilibrium samarium:	0.5 % $\Delta k/k$
Other fission products:	1.6 % $\Delta k/k$
Temperature coefficient:	5.8 % $\Delta k/k$
Total control available:	15.4 % $\Delta k/k$

Heat Transfer Data

Coolant

Type:	light water
Total volume:	2,247 liters
Volume in core:	110.89 liters
Flow:	4,000 gpm
Temperature	
—inlet:	431° F
—outlet:	450° F
Operating pressure:	1,200 psia
Pressure drop	
—reactor:	3.15 psia
—core:	1.75 psia
Core channel velocity:	2.5–5.6 fps

Heat flux

Max/avg ratio	
—axial:	2.79
—radial:	1.384
Core—average:	55,900 Btu/hr/ft³
—maximum:	215,800 Btu/hr/ft³

tear along perforation

This foldout is removable.

NUCLEONICS REACTOR FILE . . . NO. 2

Reactors on the Line

APPR

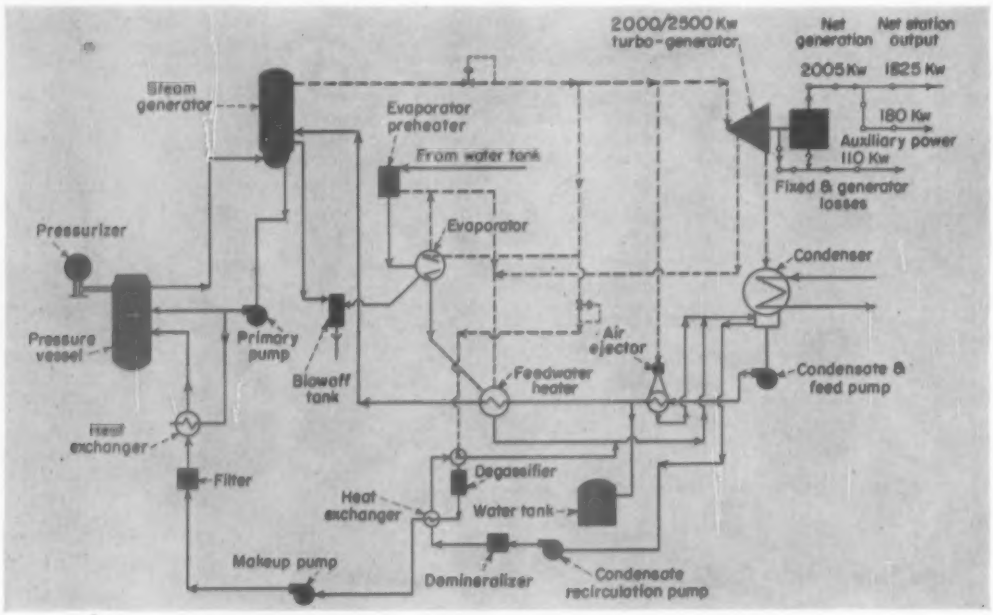
Army Package Power Reactor

APPR on the Line

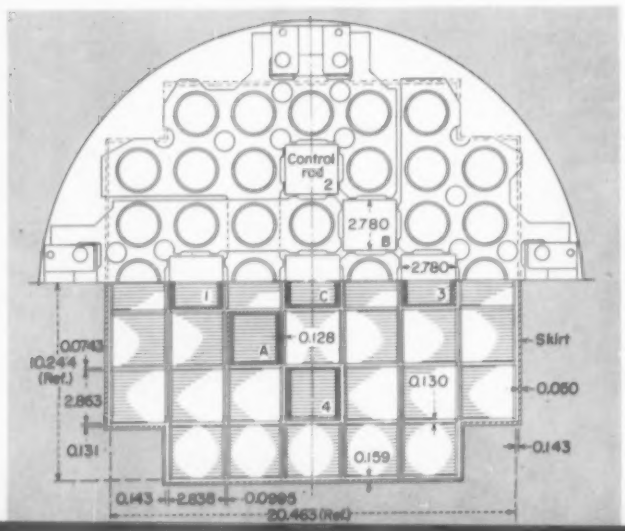
APPR-1 went critical on April 8, 1957 and generated electrical power on April 15. During the period April 15–20, the reactor reached its rated full power level of 10 Mw (heat) during low- and high-power performance tests. Final testing of APPR-1 was to be a 700-hr test with no more than 40 hr of down time permitted. This test was begun on June 2 and completed July 2 with a total down time of only 8 hr, most of which went toward the adjustment or recalibration of plant components.

During most of the 700-hr test, electricity was generated at a rate exceeding the design output of the plant with more than 1,000 Mwh being produced. Several measurements were made during the test, and the reactor demonstrated that it could be adequately cooled by thermal convection in the event of loss of primary coolant flow.

Among the significant characteristics of APPR-1 to come out of the 700-hr test was its response to load demand—the stability of the reactor exceeded all expectations. As a further indication of its performance, on July 9 the reactor was taken from full load to station load, resynchronized and returned to full load five times within an hour and 25 min.



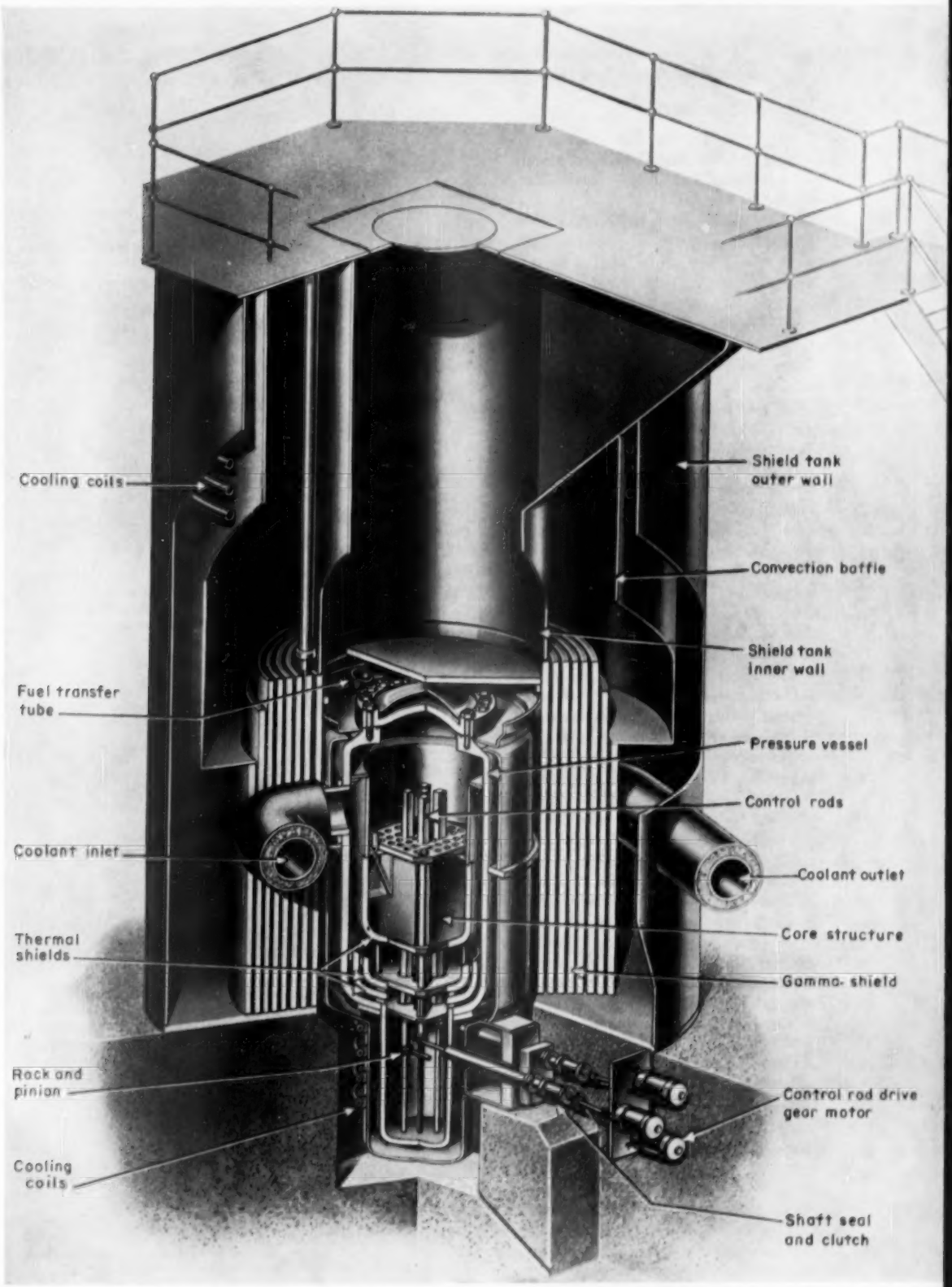
1 Schematic flow diagram shows primary and secondary systems of APPR. Auxiliary systems include makeup and water-purification equipment



2 Cross sectional view shows half of core. Shim control rods are numbered 1, 2, 3 and 4. Safety rods are lettered A and B. Regulating rod is C

tear along perforation

This foldout is removable.



3 Only five of seven control rods are shown in this cutaway view of reactor. Shown are four shim and one regulating rod. Two safety rods are completely in core. Vertical pipe showing in upper left contains five ion chambers. Primary coolant inlet and outlet pipes bend at right angles to prevent direct streaming of radiation

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Description of APPR

The first Army Package Power Reactor (APPR-1) is a pressurized water reactor using fully enriched uranium as fuel. It is the prototype of a plant suitable for generating electrical power at advanced bases of our nation's defense network. The principal advantage of a nuclear power plant for this application lies in the elimination of all but a small fraction of the logistical effort required to support a conventional power plant.

The word *package* in the name does *not* mean that it is *portable* in the sense that, once it is set up, it can be dismantled and transported to a new site. It only means that, after fabrication, each component can be packaged in boxes no more than 7 ft square by 18 ft long and weighing no more than 10 tons to be flown to the advanced base (where the APPR can be assembled in six months or less).

Pressure Vessel and Shield Tank

The pressure vessel is a cylinder with ellipsoidal heads fabricated from SA 212 (grade B) carbon steel and clad on the inside with stainless steel. An extension is welded to the lower head to enclose the rack and pinion of the control rod drive mechanisms. The extension is an 18-in. i.d. cylinder 3 ft long and 1½ in. thick.

A dish-shaped cover 2¾ in. thick is secured by 16 studs to a reinforcing ring that is welded to the circular opening in the upper head of the pressure vessel. The closure employs a soft stainless steel octagonal-shaped gasket ¾ in. wide.

Surrounding the pressure vessel, from the reinforcing ring down and around the extension, is a ⅜-in. steel shell. Between the shell and the vessel wall is 4 in. of glass wool insulation. The vessel and shell are supported by means of a ring resting on another ring around the 2-in. thick portion of the inner shield tank wall. The space between the shell and the inner tank wall is void.

The outer shield tank wall is 6.7 ft in diameter, 16.8 ft high and 0.4 in. thick. The inner wall is 2.66 ft in diameter. Between the inner and outer walls are seven concentric steel cylinders most of which are 9 ft high and all of which are 2 in. thick. The cylinders are separated by a 1-in. water gap, bringing the total radial thickness of this gamma shielding to 23 in. Neutron shielding is provided by the remaining water-filled spaces between the inner and outer tank walls.

Above the pressure vessel cover is a removable iron disk 2 in. thick. Between the cover and this disk is 4 in. of glass wool insulation. Above the disk, in the well formed by the inner tank wall, is a 9-ft column of water.

Core and Support Structure

The reactor core structure consists essentially of a lower-grid-plate assembly, skirt and upper grid plate. The function of the grid plates is to position the fuel rods and guide the control rods in the core. The upper grid is removable. After the fuel rods have been loaded into the core, the upper grid plate is bolted to the lower-grid-plate assembly through studs rising from the four corners of the lower assembly. This action compresses the springs around the top of the fuel rods.

The core support structure is bolted to brackets on the vessel wall just above the coolant inlet and outlet nozzles. The support structure serves the triple purpose of (a) supporting the core structure, (b) providing a thermal shield, and (c) providing a baffle to direct the flow of incoming coolant to the bottom of the pressure vessel (the outlet nozzle pierces the support structure).

Control Rods and Drives

The control rod "basket" is a stainless steel square tube 60½ in. long. Openings are provided at the lower and upper ends of the basket to permit coolant to flow through the rod. Inside the basket are the absorber and follower sections. The absorber section is a square tube fabricated of B_4C (enriched in B^{10}) and stainless steel powders by the picture-frame technique. The follower section contains 16 fuel plates.

The control rods are supported laterally at the upper end by sliding through the upper grid plate of the core structure and at the lower end by the pinion and roller of the control rod drive mechanism. A drive shaft extends from the pinion out through the wall of the pressure vessel extension and connects, through a magnetic clutch, to a gear motor. A labyrinth seal, consisting of a series of floating rings around the shaft, provides a small, controlled amount of leakage from the pressure vessel extension.

The reactivity of the reactor is increased when the control rods are raised such that the absorber section in the upper portion of the rod is "pushed" out of the core by the follower (fuel) section. The reactor is scrammed by de-energizing the magnetic clutch, allowing the absorber section to fall back into the core.

Fuel Rods

The plate-type fuel rods used in APPR-1 contain rectangular plates fabricated of UO_2, B_4C (enriched in B^{10}) and stainless steel powders by the picture-frame technique. The small amount of burnable poison (B_4C) increases the reactor's endurance. The plate is clad all over with stainless steel, bringing its dimensions to 23 in. long, 2.76 in. wide, and 0.03 in. thick.

Each fuel rod contains 18 such plates; two stainless steel side plates 27 in. long, 2.863 in. wide, 0.05 in. thick; and two stainless steel end boxes. The fuel and side plates are brazed together with a nominal water gap of 0.133 in. between them, and the end boxes are attached by fusion welding. The metal-to-water ratio of the fuel rod is 0.256.

Vapor Container

The vapor container is a 36-ft diameter, 64-ft high cylinder with hemispherical heads. The center cylindrical section is constructed of ⅞-in. steel plate and the heads of ½-in. steel plate. This steel shell is lined on the inside with a 2-ft thick layer of concrete that is covered with a No. 10 gage steel liner. The lower head is completely below ground level, thus permitting the reactor to be constructed with the pressure vessel (and core) entirely below ground level.

The manhole (6.58-ft i.d.) in the top of the vapor container, through which the equipment entered during construction, is seal-welded around a gasketed and bolted 2½-in. thick cover. The manhole at ground level is 9 ft long and 4.5 ft in diameter. It has gasketed and bolted 2½-in. covers at either end and is completely filled with water during reactor operation.

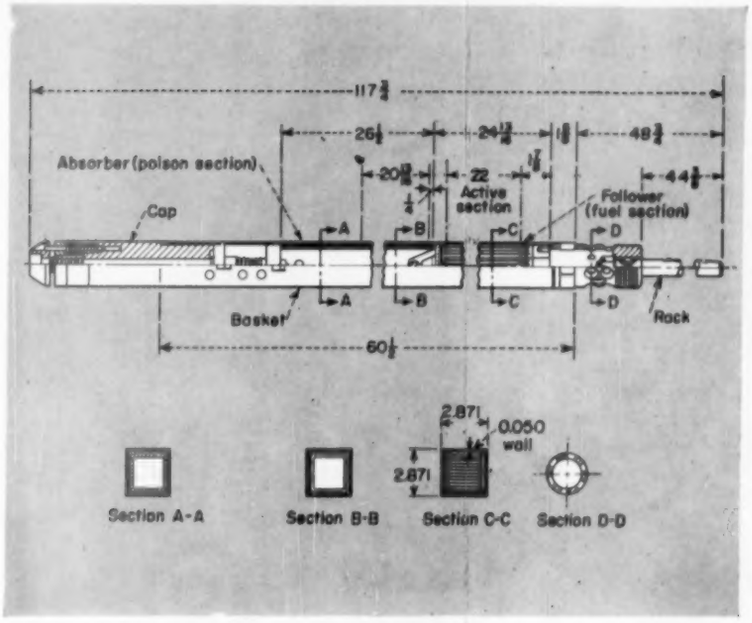
To reduce the internal pressure and container-wall temperature gradient that would result from an accidental rupture of any of the components in the vapor container, two water-spray nozzles are located inside the tip of the shell dome. In the event of such an accident, water would be sprayed into all parts of the shell to condense any steam that was released.

The major components in the vapor container, other than the reactor, are the pressurizer, primary coolant circulating pumps, and the steam generator.

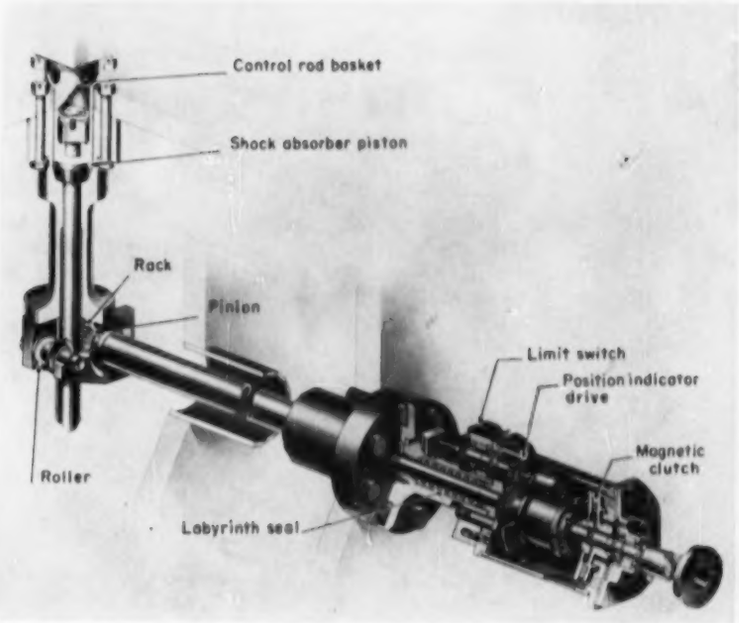
Pressurizer. The 1,200-psia operating pressure of the primary system is maintained by two 50-kw immersion heaters housed in a pressurizer comprised of a sphere 45 in. in diameter mounted on a cylinder 16 in. in diameter and 54 in. long. The pressurizer is designed to absorb fluctuations in the primary coolant volume resulting from temperature changes due to load changes.

Circulating pumps. Primary coolant is circulated through the loop at a rate of 4,000 gpm by one of two centrifugal canned rotor pumps with 28-ft operating heads. The standby pump is automatically started in the event of an electrical failure in the operating pump. Both pumps are fabricated primarily of stainless steel.

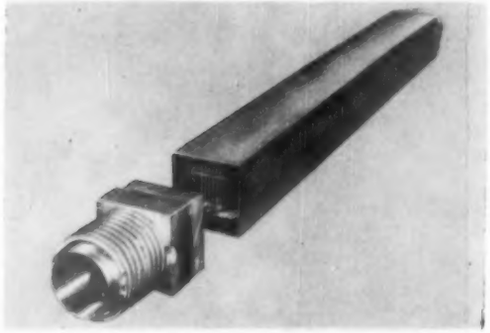
Steam generator. The steam generator is of the vertical, double-pass, U-tube type. The tubes, partition, shrouds, and baffle are fabricated of type 304 stainless steel; the shell, tube sheet, and nozzles, of SA 212 carbon steel clad with 304 stainless. There are two bundles of tubes, one, the steam generating section, consisting of 326 tubes and the other, the superheater section, consisting of 44 tubes. The outside diameter of all tubes is ¾ in., and the wall thickness is 0.062 in. The total effective heat-transfer surface of the generating section is 836 ft^2, and that of the superheater section is 194 ft^2. Steam (407° F, 200 psia) is generated at the rate of 34,270 lb/hr from 250° F, 35-psia feedwater containing excess hydrogen to deter corrosion.



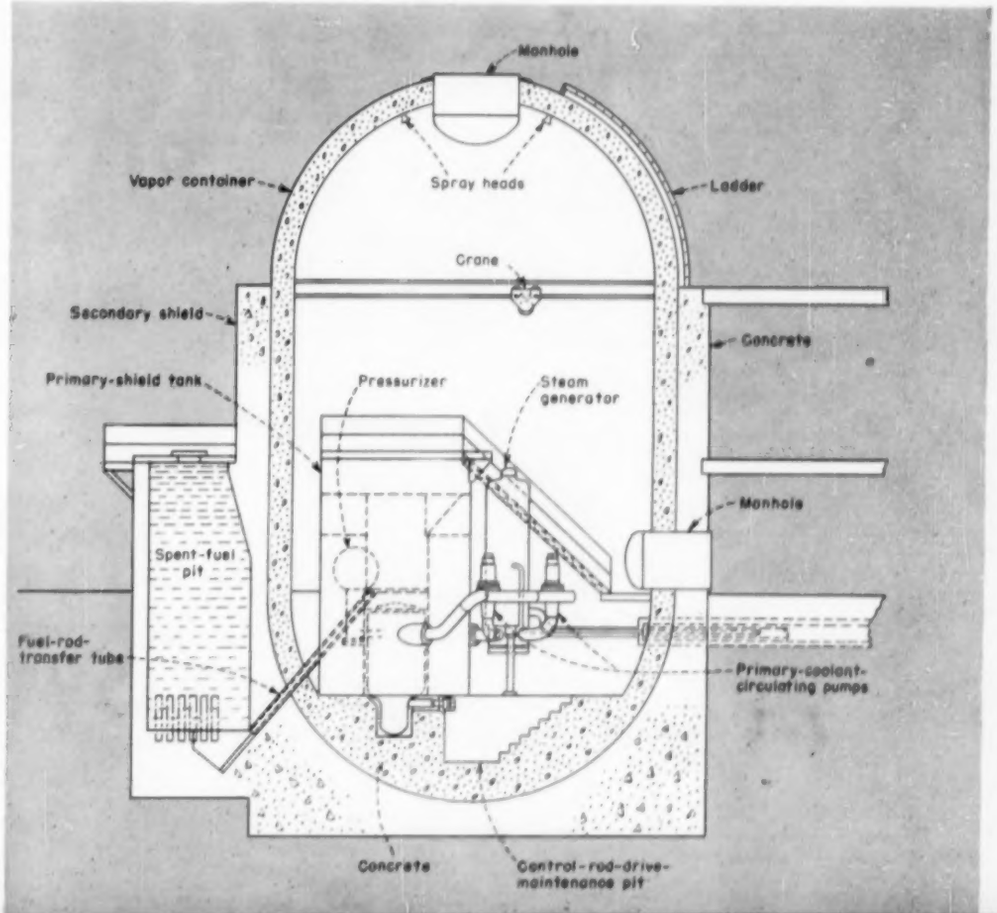
4 Sectioned views of control rod. Cap cannot be installed on rod unless follower and absorber sections have been installed properly. Lower end of rod (where rack and rod are joined) is piston in dashpot of drive-mechanism mounting. Rack engages pinion in pressure vessel extension



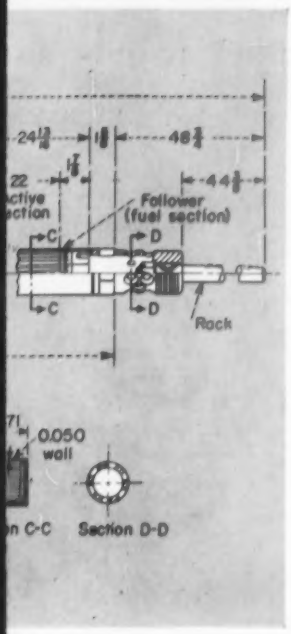
5 Control drive mechanism (less gear motor and shaft). Location of drive at bottom of reactor vessel permits removal of vessel cover for refueling without necessity of disconnecting drives. Also, primary coolant system need not be depressurized and drained for maintenance of motor, clutch or seal



6 Fuel element is about 3 ft long and 2¾ in. square. Upper-grid-plate hole fits over end box in foreground, compressing spring and giving lateral support. Core consists of 38 such elements with seven similar elements being used in fuel section of control rods



7 Section through vapor container shows 3-ft thick concrete secondary shield and 28-ft deep spent fuel pit. Pit is lined with tile and has cadmium plated steel storage racks. Spent fuel elements are transferred to pit through tube that is sealed during reactor operation



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Lower end of rod (where rack
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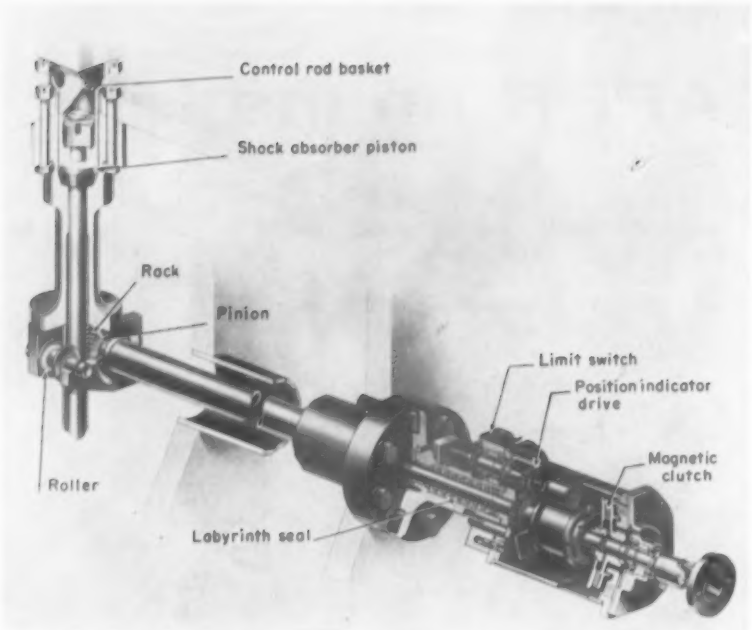

5 Control drive mechanism (less gear motor and shaft). Location of drive at bottom of reactor vessel permits removal of vessel cover for refueling without necessity of disconnecting drives. Also, primary coolant system need not be depressurized and drained for maintenance of motor, clutch or seal

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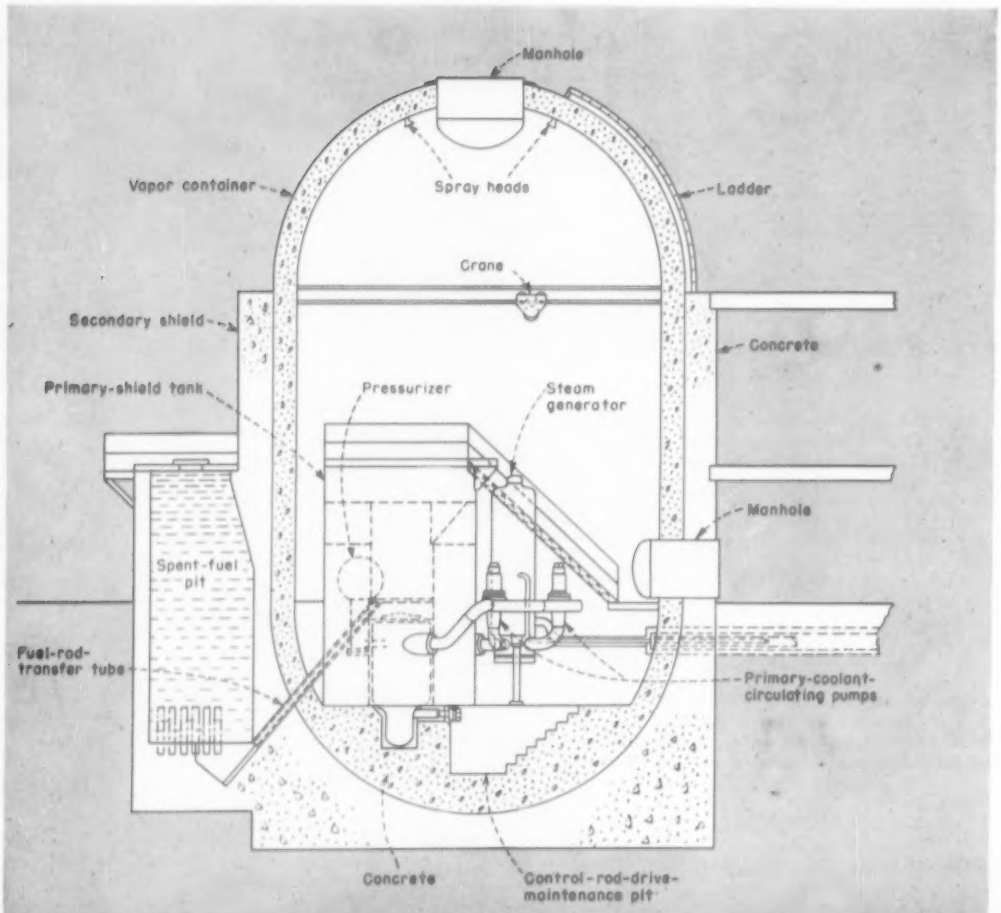


The American Nuclear Society Meets and Talks . . .

MEETINGS are a mainstay of technical communication. The formal sessions provide a forum for discussion of new ideas and further progress in the implementation of old ones. But of equal importance at least are the opportunities for informal discussion with others in the field. This "corridor talk," free from the constraints of public discussion, goes to the heart of the matter under discussion: "I don't get it." "We tried the same thing years ago and it didn't work." "It won't work. I don't know why. It just won't work" . . . can be said a lot more readily when the group consists of four instead of four hundred.

Nuclear people proved no exception to the rule that more people can be found in the corridors than in listening to the papers when the American Nuclear Society met in Pittsburgh for its third annual meeting June 10–12. This was no reflection on the sessions, which were excellent (see pp. 62–67 for highlights), rather it reflected the insatiable desire to talk to old friends, collect new rumors and, maybe, a new job.

NUCLEONICS' photographer caught some of the corridor talk in progress. For those not fortunate enough to have been there themselves we hope this conveys some of the spirit.

. . . In the Corridors . . .

"IT WOULD BE THIS BIG." Milton Edlund, who heads up physics and mathematics activities for Babcock and Wilcox in Lynchburg, Va., shows Jack Ransohoff of Washington, D. C. and Walter Walker of U. of Va. how small propulsion reactor would be if nature conformed to wishes of aeronautical designers

"HOW'S THAT NOW?" Len Koch of Argonne National Laboratory (right) makes note on conversation with M. F. Valerino, B. C. Cerutti, and H. V. Lichtenberger, all of General Nuclear Engineering Corp., Dunedin, Florida. Koch was on program committee for the ANS meeting in Pittsburgh

"WHICH SESSION YOU GOING TO?" seems to occupy Ed Mason, Raymond Brown and Carl Leyse as they pause before ANS signpost. Brown is with General Electric Co.; remaining two are with Internuclear Co., Clayton, Mo.

"ENERGIA NUCLEARE"—"NUCLEAR ENERGY." Oceans are bridged as Augusto Ancarani of Italy's AGIP Nucleare (left) listens to Ralph Deuster, Babcock and Wilcox Co. nuclear systems specialist with responsibilities in the Con Ed project

"IT ISN'T EASY." Sample in hand, Art Matheson, Manager of Metals and Controls Corp.'s nuclear division, explains fuel-element-fabrication problems to J. N. Grace of Westinghouse, Bettis Field

. . . While in the Technical Sessions . . .

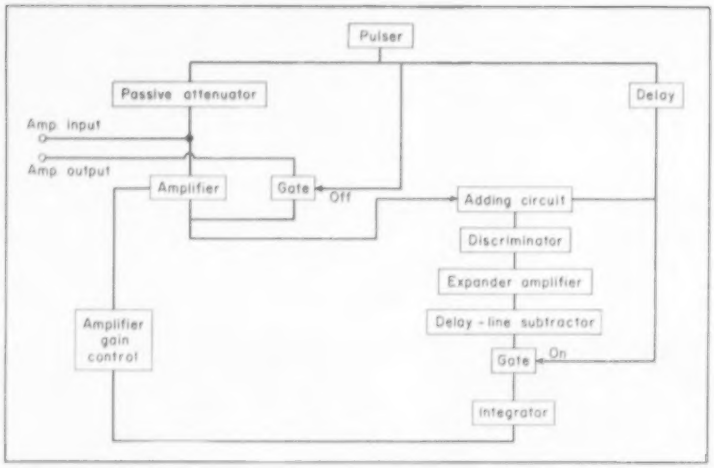
What's New in the Nuclear Field? . . .

. . . Ultrastable Amplifiers

• *K. A. McCollom, D. R. deBoisblanc and J. B. Tompson; Phillips Petroleum Co., Atomic Energy Division; Idaho Falls, Idaho.* A direct comparison of the amplitude of an untreated pulse with that of a pulse from the same source that has been attenuated and then amplified back to the same level has been used as the basis of an extremely accurate tool for testing amplifier stability and is now being proposed for use in stabilizing amplifiers to better than 0.01%.

A block diagram of the proposed amplifier (right) reveals that the reference pulse and the attenuated-then-amplified pulse pass through the same circuits wherever possible. Thus these circuits do not need to have anything like the same stability as is finally achieved. Note that both pulse trains pass through a threshold device (discriminator) that subtracts the same voltage from each pulse and then through an expander amplifier that amplifies the remainders; this again lightens the requirements on the final amplitude-comparing device whose output is used to adjust the gain of the amplifier.

A gate is provided to eliminate all stabilization pulses from the normal amplifier output.



ULTRASTABLE AMPLIFIER block diagram. Pulser output is split; test pulse goes to attenuator and amplifier, reference pulse to delay line. Two pulses are then combined in adder, decreased by fixed amount in discriminator and remainders amplified in expander. Shorted-delay-line subtractor with delay half that used above then subtracts reflected test pulse from reference pulse. Gate samples differences, which are integrated to provide corrective signal for amplifier gain

In the amplifier-comparator application the working principles are similar. A pulser and mercury switch are arranged to send alternate pulses through an attenuator and the amplifier under test or around it for reference purposes. As in the ultrastable amplifier the succeeding steps of adding, discriminating, and expanding are done by the same circuits for both sets of pulses. The next stage differs: the two sets of pulses are separated by a synchronous switch and fed to separate peak-reading voltmeters. A comparison of their outputs is a direct indication of amplifier stability.

. . . Zinc Pyrometallurgical Processing

• *J. B. Knighton, H. M. Feder, L. Burris, Jr. and A. A. Chileskas; Argonne National Laboratory; Lemont, Illinois.* Laboratory-scale experiments show that fractional crystallization of uranium in zinc provides a promising pyrometallurgical process for application to (a) decontamination of spent reactor fuels, and (b) concentration procedures for zirconium-uranium fuels.

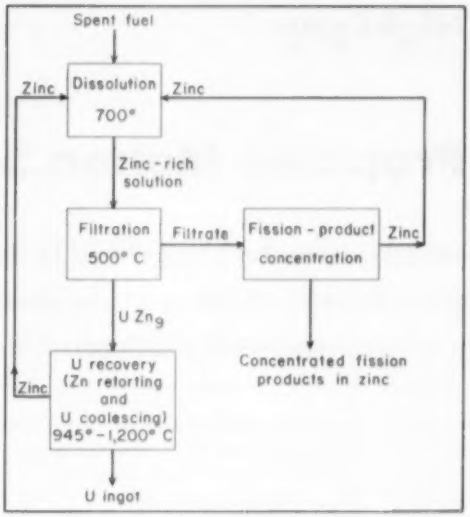
Fractional crystallization involves taking advantage of the difference in solubility of uranium and other elements in zinc. Typical of the processes that might be evolved is that shown at the right top, next page. It is significant that the compound UZn_9, which plays an important role in the U-Zn phase diagram and hence in this pyrometallurgical process, is nonpyrophoric and oxidation-resistant at room temperature. Also it can be decomposed to U and Zn by heating above 945° C, permitting the recovery of U. The use of zinc as a solvent is favored by its low cost, availability in high purity, adequate volatility and nontoxic nature.

To demonstrate the basic feasibility of the method measurements were made of the solubility of individual fission elements in zinc and in uranium-zinc systems. Ruthenium, molybdenum, barium and cesium are less soluble in zinc than uranium while rhodium, zirconium and palladium are more soluble. Such single-element studies do not tell the whole story, however, since multicomponent systems may behave differently and minor components may coprecipitate as the major component crystallizes.

Reduction of U. Another significant use of zinc in nuclear metallurgy may result from the fact that it has been found possible to reduce various U compounds with Mg in a Zn solvent. Typical reactions are:

$$UO_2 + 2\,Mg + 9\,Zn = 2\,MgO + UZn_9$$
$$UO_3 + 3\,Mg + 9\,Zn = 3\,MgO + UZn_9$$
$$UF_4 + 2\,Mg + 9\,Zn = 2\,MgF_2 + UZn_9$$

The U can be subsequently recovered from solution by the decomposition of the UZn_9 previously mentioned. The possibility of reducing uranium compounds in liquid-metal media has important implications in pyrometallurgical processing of nuclear fuels; U recovery from slags, processing irradiated oxide fuel, and preparation of uranium feed materials.



PYROPROCESSING WITH ZINC. Spent reactor fuel is taken into solution in Zn at 700° C, cooling to 500° C crystallizes UZn_9 but leaves fission products in solution to large extent because of their high solubility and/or low concentration. Filtration separates UZn_9 crystals from which U can be recovered by heating to 945° C

. . . U Alloys for Exportable Fuel Elements

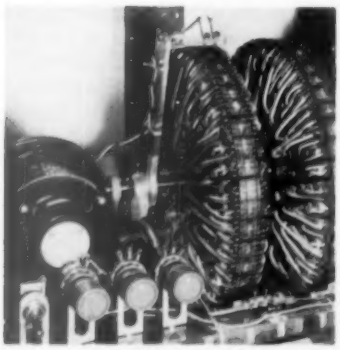
• *R. J. Beaver, W. C. Thurber and R. C. Waugh; Metallurgy Division, Oak Ridge National Laboratory; Oak Ridge, Tennessee.* The limitation to 20% enrichment of fuel supplied for research reactors under the U. S. Atoms-for-Peace plan has significant consequences for the metallurgy of fuel thus supplied. Whereas a domestic MTR-type fuel element employing 93%-enriched U can be made of aluminum alloy containing ~18 wt % U, exportable elements must have about 48 wt % U to make up for the lower enrichment permitted. The increased U concentration results in decreased ductility and subsequent fabrication problems.

The metallurgy division at ORNL has an extensive program devoted to development of suitable fuel materials for exportable aluminum plate-type fuel elements. Two approaches show promise: the addition of small amounts of Si to improve workability and the use of powder-metallurgical techniques to incorporate ~50 wt % of uranium oxides in aluminum.

The Si-modified alloy is based on the observation that 2–3 wt % of Si completely suppress the transformation of UAl_3 to UAl_4, thus allowing the primary nucleating compound UAl_3 to be retained as the stable phase down to room temperature. Casting in graphite molds was no longer troubled by hot tears and uneven grain size. Fabrication runs using the "picture-frame" technique showed a drastic decrease in the number of edge cracks and led to successful attempts at bare rolling, which is impossible with the unmodified alloy.

The powder-metallurgical studies are not as far along but already it has been established that U_3O_8 prepared by calcining $UO_3 \cdot H_2O$ can be incorporated into an aluminum matrix in more than adequate weight percentages. Volume increase, even after 160 hr at 600° C, is only 0.35%. UO_3-powder samples on the other hand exhibit a 30% volume change after only 24 hr, part of a general pattern that makes UO_3 seem unsuitable.

. . . Simulation of Circulating-Fuel Reactors



DELAY WHEELS for simulating time spent by circulating fuel in external circuit use capacitors to carry charge between amplifiers

• *Theodore Gogniat, Atomic Power Dept., Westinghouse Electric Corp., Pittsburgh, Pa.* The usual electrical analog representations for the kinetic behavior of a reactor (NU, May '57, p. 76) must be modified in the case of a circulating-fuel reactor to account for the fact that some delayed-neutron precursors are swept out with the fuel. Some of the precursors will decay, leading to the emission of neutrons in the external loop, away from the core, while others will complete the entire external cycle before decaying. In any event account must be taken of these effects in the simulation of reactor kinetics.

A key problem in the simulation is how to represent the time delay. One device that serves the purpose well is shown at the left. Capacitors are mounted on a rotating wheel so that they are first brought in contact with the output of one amplifier and, a certain time later, placed between the input and output of a second amplifier. Thus the information is stored on the capacitor while delay is provided by the finite transit time of the wheel.

Similar delay wheels are used to account for mass-transport delays in temperature effects as the coolant goes from reactor to boiler and back.

ORNL Proposes Molten Salt Reactor

A homogeneous power reactor using U and Th dissolved in molten salt promises excellent thermal efficiency at low operating pressures if the problem of high-temperature-salt corrosion can be solved

A NEW KIND of power reactor using fuel dissolved in molten fluoride salt was the subject of a special session presented by a series of speakers from Oak Ridge National Laboratory led by Alvin Weinberg, laboratory director. This is the first release of Oak Ridge's knowledge in this field since Weinberg's disclosure in May (NU, June '57, 20) that the Laboratory had built and operated an experimental 2.5-Mw reactor of this kind as a part of the Aircraft Nuclear Propulsion effort. Weinberg started the session with a discussion of the merits of the fluoride reactor as a commercial power reactor. He was followed by three more speakers who summarized the information about the Aircraft Reactor Experiment itself: G. A. Christy—design and construction, W. F. Ergen—physics and W. B. Cottrell—operation.

Weinberg suggested that a commercial design, like the ARE, would be a circulating-fuel type using a molten solution of fluoride salts and UF_4. It would therefore be very similar to the Liquid Metal Fuel Reactor now under development at Brookhaven. The molten salt, however, would have advantages over the U-Bi solution used in LMFR. Namely it can dissolve larger concentrations of U and can also dissolve thorium compounds. (Thorium is insoluble in Bi.) On the other hand the molten salt has a higher melting point (1,000° F) than Bi. Just like LMFR the salt reactor would have corrosion and mass-transfer worries.

Oak Ridge Backs Liquid Fuel

Weinberg began by reaffirming ORNL's faith in the economic promise of liquid-fuel power reactors. This feeling is reflected in the Laboratory's current program for civilian power which is devoted almost entirely to the aqueous homogeneous reactor concept. In fact the Oak Ridge attempt is presently the world's foremost effort in the field of liquid-fuel reactors.

Although Weinberg feels that the aqueous system is still very much in the running, he said that it has three main drawbacks:

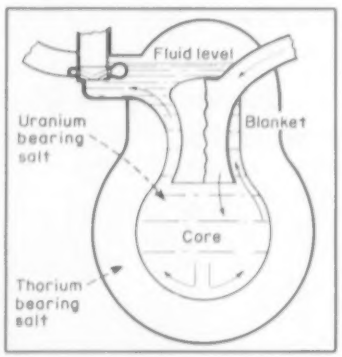
a. Like all aqueous power reactors it must operate at a high pressure for even a modest thermal efficiency.

b. No thorium compound that could be used in practice is soluble in water (the blanket of the two-region aqueous homogeneous reactor is a slurry).

c. The radiolytic decomposition of water into hydrogen and oxygen is an intrinsic hazard requiring elaborate disposal equipment.

Fluoride Salt's Advantages

The LMFR approach of using the U-Bi eutectic eliminates the first and third problems but still suffers from Th insolubility. In searching for an alternative approach, R. C. Briant first suggested that molten-fluoride fuels would solve all three complaints. Molten fluorides of the alkali metals, beryllium, or zirconium dissolve either UF_4 or ThF_4, do not require high pressure and do not decompose under radiation. The compositions and properties of the most interesting fluorides are listed in the table.



SALT REACTOR design for commercial power application. Two region converter uses molten core salt (70% Li^7F, 30% BeF_2) to provide neutron moderation and to carry $U^{233}F_4$ fuel. Blanket is solution of ThF_4 in LiF. Both core and blanket solutions are circulated to external heat exchangers to remove total of 600 Mw thermal power

In addition to the three specific advantages cited above, the fluoride salts have other attractive features. Their neutron absorption cross sections are conveniently small. As can be seen from the table their heat-transfer properties are roughly the same as those of water. The higher viscosity of the salts compared with that of water is offset by their superior conductivity. In addition to having good solubility for U and Th there is the possibility (as yet untested) that the fluoride salts will also be able to dissolve practical amounts of plutonium.

All of these advantages led Weinberg to express the feeling that the idea of using molten fluorides does not represent merely a variation on the LMFR but opens the way to a completely new family of reactors. In his own words, " . . . the fused-salt reactors can be made the basis of a whole new class of reactors each of which may include numerous embodiments."

Fluoride-Salt Drawbacks

Although the fluorides appear perfect in many respects, Weinberg was careful to point out that there is also a debit side. First of all the salt reactor, like all circulating-fuel reactors, is faced with the problems of guaranteeing leak-tightness and providing for component maintenance. Besides these it shares with LMFR the problems of container

Physical Properties of Various Salt Mixtures

Salt	Melting point (° C)	Density at 700° C (g/cm^3)	Viscosity at 700° C (centipoises)	Thermal Conductivity (cal/sec cm ° C)	Heat Capacity (cal/g ° C)	Prandtl's Number
53.5% NaF, 40% ZrF_4, 6.5% UF_4	540	3.27	5.7	0.005	0.24	2.74
71% LiF, 16% BeF_2, 12% ThF_4, 1% UF_4	525	3.25	7.1		0.37	
67% LiF, 30.5% BeF_2, 2.5% UF_4	464	2.10	5.5		0.57	
Water (20° C)			1.00	0.00143	1	7

corrosion, high fuel inventory, and high coolant-melting point.

As with the LMFR, difficulties with corrosion and mass transfer may prove to be a major stumbling block for fluoride systems. ARE did not operate long enough to prove anything one way or the other about this question. During its lifetime the system logged a total of 462 hours of operation at 1,200° F or above. Clearly this span of endurance is trivial compared to the lifetimes (20–30 yrs) required of commercial power reactors.

Oak Ridge has undoubtedly run salt loops to test material corrosion and mass transfer as part of the supporting effort for the ARE project. Presumably the choice of an all-Inconel primary system for the ARE is a reflection of the results of such tests. The details of any knowledge Oak Ridge has accumulated on this subject, however, have yet to be disclosed. Weinberg only alluded to this knowledge when he summed up the corrosion picture: ". . . our considerable experience with these systems strongly suggests that the corrosion problem is a tractable one."

Because the moderating properties of salt are inferior to those of D_2O, the salt reactor, requires a higher concentration of U in solution than the aqueous reactor. As a result the material efficiency—the power output per kilogram of fuel inventory—is rather low. This disadvantage tends to reduce the gains resulting from the higher thermal efficiency of the salt systems.

Finally the high melting point of the fluoride salts (about 1,000° F) creates operational problems and can present a possible hazard. Provisions must be made for preheating the primary system above the melting point and for transfering the molten salt to and from the reactor. While it is in the reactor the salt must at all times be kept above the melting point. If it should freeze at any point in the primary system serious consequences could result.*

Weinberg suggested that the successful operating experience of the ARE has shown that a system using the high-melting-point salt can at least be run. The question remains as to whether or not the extra design complications imposed by the high melting point would be too much for a commercial power reactor.

Possible Applications

After looking at the over-all pros and cons, Weinberg reviewed the prospects for fluoride salt in various reactor applications. First he pointed out that from the economic angle the high-temperature liquid-fuel reactor is ideally suited as a straight U^{235} burner. Since the thermal efficiency is high and there are no full fabrication costs, one could expect operating fuel costs as low as 2–3 mills/kwh. If Pu turns out to be soluble in fluoride, the reactor would make an equally good Pu burner.

Likewise the salt reactor looks good as a U^{233}-Th breeder. Because of the poorer nuclear properties of the fluorides the breeding ratio would be somewhat smaller than for a D_2O system. However ORNL calculations indicate the breeding ratio of the salt system will still be pretty close to unity.

For fast reactors salt does not look promising. A fluoride system is out of the question because it is too good a moderator. Chlorides would satisfy this objection but would have to be free of the neutron-absorbing Cl^{35}.

Proposed Design

Oak Ridge has been busy inventing salt reactor designs for commercial power application. A group under H. G. MacPherson has made the most exhaustive effort so far. A drawing of their proposed reactor is shown in the figure. It will be a two-region homogeneous system with a core 6 ft in diameter surrounded by a 2-ft-thick blanket. The core salt, a mixture of 70% Li^7F and 30% BeF_2, will act as the moderator. In addition to $U^{235}F_4$ it may also contain some ThF_4. The blanket will be the eutectic of Li^7F and ThF_4 or mixtures of this and the basic core salt. The melting point of the core material is 867° F and 1,080° F for the blanket.

The core and blanket salts are circulated to external intermediate heat exchangers, six in parallel for the core and two in parallel for the blanket. An intermediate fluid (probably sodium) carries the heat from these exchangers to the water boilers, superheaters, and reheaters. The core is designed for a total power of 600 Mw (at a power density of 187 watts/cm^3). A 1,200° F fuel outlet temperature produces steam at 1,000° F and 1,800 psi and gives a net power output of 240 Mw.

When the fission-product concentration of the core salt mixture becomes too high, the unburned uranium (including the even-numbered isotopes) is separated out by the volatility process and returned to the core with fresh salt. The blanket would be processed by the same method to remove the U^{233}, which will be fed into the core as makeup fuel. The blanket salt, unlike the core salt, would be reused.

The simplicity of the fuel cycle is easy on fuel costs. ORNL currently operates a pilot plant for the volatility process. Using cost figures for this plant and assuming \$17/gm for U^{235}, a 4% inventory charge and an 80% load factor, the proposed reactor would have a fuel cost of 2.5 mills/kwh. Plans for building the proposed salt reactor are at the moment indefinite.

* For example suppose for some reason (e.g. accidental reduction in pumping power) the salt should freeze in the heat exchanger while the reactor is running at power. Even if the reactor is scrammed immediately, because of the restriction in flow the reactor might melt down from afterheat. Even assuming a meltdown could be avoided thawing out the frozen heat exchanger without rupturing some of the tubes would very likely prove impossible.

Moderator Control Extends Burnup

Shim control in water reactors can be achieved by diluting D_2O with H_2O. This strategy markedly increases fuel burnup and flattens core power density. A D_2O reprocessing plant is required but its cost does not appear unreasonable

A NEW METHOD of shim control for water moderated reactors was outlined by M. C. Edlund and G. K. Rhode, both from the Atomic Energy Division of Babcock and Wilcox. They propose to compensate for the reactivity loss due to burnup in a water-moderated power reactor by diluting the heavy-water moderator with light water as the fuel is consumed. The change in moderator composition causes a shift in the neutron spectrum, making it more thermal. Neutrons originally captured by the breeding material in the resonance region are then free to cause fissions in the fuel. Compared with the conventional method of shim control (withdrawing neutron absorbing rods), the new method allows much higher burnup without lowering the conversion ratio and gives a more uniform power distribution in the core. The cost of repurifying the diluted heavy water appears to be reasonable for a practical size power plant.

Burnup vs. Conversion

Power reactors with conventional shim control are faced with a dilemna in trying simultaneously to obtain high burnup and high conversion ratio. To achieve high burnup the core must be loaded at startup with a large amount of excess fuel. In conventional reactors the positive reactivity of this excess fuel is cancelled out by the presence of neutron absorbing shim rods which are slowly withdrawn as the fuel burns. However the neutrons absorbed in the shim rods are wasted as far as the conversion ratio is concerned. A reactor loaded with a small excess mass will have a higher average conversion ratio during its lifetime than a reactor loaded with a large excess mass. Thus the economic goals of high fuel burnup and high conversion are mutually exclusive for power reactors having ordinary shim control.

Obviously the answer to this situation is to find some way of providing shim control by absorbing the excess neutrons in the fertile material rather than in a control rod poison. The spectral shift reactor proposed by Edlund and Rhode performs precisely this feat. The reactor would be of the

Testing Reactor Enclosure Tightness

LIKE MOST power reactors the Boiling Water Reactor recently constructed by the General Electric Co. at the Vallecitos Atomic Laboratory is housed in an airtight steel containment shell. To insure safety the design specifications of the shell required the vessel to lose a maximum of 1% of its rated pressure (45 psig) within a 24 hour period through leakage. After the shell had been installed and accepted from the contractor, the reactor operations group was faced with the problem of finding out if the vessel leakage was, in fact; below this limit. The main difficulty was that daily temperature variations cause changes in absolute pressure large enough to conceal any pressure loss due to leaks. D. L. Layton and S. Untermyer, both from the Vallecitos Atomic Laboratory of the General Electric Co., reported on how they bypassed this problem and proved that the BWR enclosure leakage was negligible.

Temperature Difficulties

At first glance measuring the leakage of the reactor container would seem to involve only a straight-forward determination of the variation of the absolute pressure in the container over a period of time. The situation is complicated by the fact that the ambient temperature normally varies 15° to 30° F within twenty-four hours at the site. With the sun striking the steel skin of the vessel, even greater temperature variations could be expected inside the vessel.

Clearly the changes in absolute pressure caused by these temperature fluctuations would completely mask a 1% pressure change due to leakage.

The problem was solved by observing the pressure difference between the vessel and a system of airtight drums contained inside the vessel. Since the temperature of the air in the drums is always very nearly the same as that of the air in the container, the pressure difference is not affected by the daily temperature changes and can be used to make an accurate determination of the container leakage rate.

A water manometer was used to monitor the leakage rate. One leg of the manometer was connected to the pressure vessel and the other was connected to a tank system within the vessel. The manometer provided a very sensitive indication of pressure differential between the two systems. (One pound per square inch corresponded to 27.67 inches differential on the manometer.) At the beginning of the test the

pressurized water variety, the water serving as both moderator and coolant. At startup the moderator is about 85% D_2O and 15% H_2O. The nuclear configuration of the system is adjusted so that under this condition the positive reactivity of the excess fuel is offset by resonance capture in the fertile material. As the excess reactivity decreases because of fuel burnup and fission product formation, the resonance capture of the fertile material is correspondingly reduced by diluting the heavy water still further with light water. This comes about because of the superior slowing down power of light water compared with heavy water. As the light water is introduced the neutrons slow down more quickly to thermal energies so that they have less chance to be captured in the resonance region by the fertile material. In this way gradual dilution of the moderator with light water gives exact shim control at all points during the lifetime of the core and at the same time provides excellent neutron economy.

An additional advantage of the spectral shift shim control is that the local power density can be kept uniform throughout the core. In the conventional reactor the motion of the shim rods necessarily causes changes in the flux pattern. Thus at best the power can be made flat for only one position of the rods. At all other positions the power density will necessarily be nonuniform. In the spectral shift reactor, however, the neutron flux pattern will to first approximation remain unchanged during the core lifetime. Thus this reactor can be designed to run at a more uniform power density at all times. Since usually more power can be extracted from a given size core if the power density is more uniform, this is another economic advantage for the spectral shift reactor.

Fuel Cycle Calculations

Edlund and Rhode summarized the results of lifetime reactivity studies made for a hypothetical spectral-shift-pressurized-water-reactor. The fuel was assumed to be an oxide contained in Zircaloy 2 fuel rods. Calculations were made for the U^{238}-U^{235}, the Th-U^{235} and the Th-U^{233} systems. The calculations showed that excess fuel equivalent to as much as 50% excess reactivity can be accommodated by the spectral shift system. This greatly extends the limits on fuel burnup imposed by reactivity loss in water reactors. For instance it was found that a Th-U^{235} reactor using a straight D_2O moderator and conventional shim control could reach burnup of 16,000 Mwd/ton while the spectral shift scheme gave a burnup of 42,000 Mwd/ton. A burnup of 28,000 Mwd/ton and an average conversion ratio of 0.63 were achieved by a spectral-shift reactor burning U^{238}-U^{235}. (Recyling the Pu would give 34,000 Mwd/ton.) The Th-U^{233} combination is expected to give even higher burnups for equally good conversion ratios.

D_2O Distillation Plant

The one drawback to the spectral shift idea is that the reactor plant would have to have some means of purifying the heavy water that was diluted during the reactor run. This job would most likely be done by a small distillation plant located on the site that would reconcentrate the D_2O from the primary cooling circuit as needed. The question immediately arises as to whether the cost of operating such a plant might not cancel out all of the economic advantages discussed above. Edlund and Rhode find that this is not the case. Calculations for a hypothetical 500 Mw power plant show that the distillation plant would cost only $1.5 million to build and $150,000 per year to operate.

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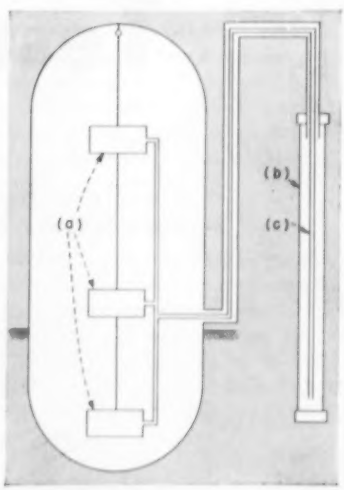
two systems were at the same pressure since they were connected by the empty manometer. After water was placed in the manometer, any difference in pressure due to leaks in the reactor containment vessel would be indicated by a differential between the heights of the two water legs of the manometer.

Test Arrangement

Heavy gasoline drums were used for the tank system. Their walls were thick enough not to bulge under the pressure differential yet thin enough to respond rapidly to temperature changes so that the corresponding pressure changes would be quickly equalized on both legs of the manometer. The barrels were suspended by a steel cable in the center of the vessel.

The pressure line from the drums was placed inside the one inch pipe that served as the pressure line from the reactor container to the manometer location in the BWR control building. The lines were installed in this manner



LEAK TEST arrangement for G. E. BWR containment shell. Manometer legs (b, c) detect shell leakage by measuring pressure difference between shell and airtight system of barrels (a). Pressure changes due to temperature fluctuations are canceled out since barrels are at temperature of shell

to minimize the effect of any minute leaks that might be in the tank pressure line.

Results

The weather conditions during the test were quite consistent, and as a result the daily vessel pressure cycles caused by the temperature were repetitive during the 2.3 day period. Pressure differentials caused by the temperature effects on the two legs of the manometer were well compensated for by the three barrel system arrangement within the vessel.

A plot of the manometer readings shows that there was no measurable pressure variations caused by leakage. During the night hours when there was little effect from temperature on the vessel, the readings were about minus ½ inch on each evening for three consecutive evenings. This reading is estimated to be reliable to plus or minus ⅛ inch. Thus the leakage did not exceed 0.02% per day.

SPERT-III is capable of operation at 60 Mw for 30 min at 2,500 psi and 650° F. It will be used to study basic transient characteristics and reactor safety under conditions encountered in high-powered pressurized-water reactors

Special Power Excursion Reactor Test III

By T. R. WILSON
Phillips Petroleum Co., Idaho Falls, Idaho

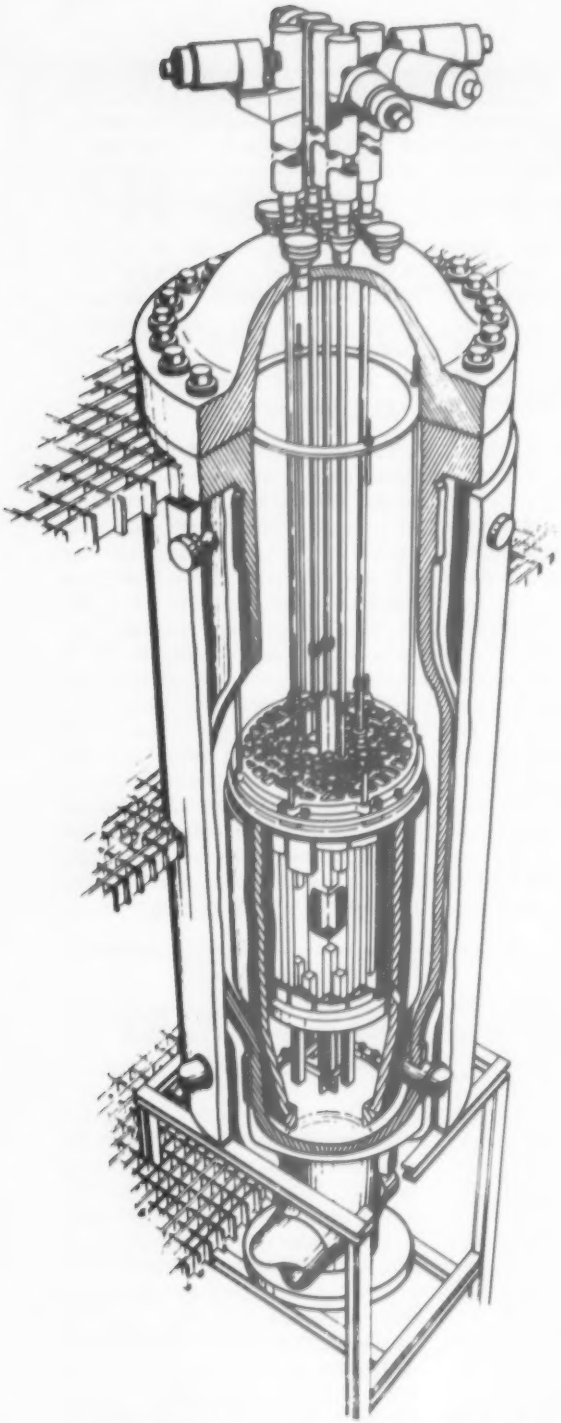


FIG. 1. SPERT-III reactor. Minimum of shielding is required because control center is about ½ mi away

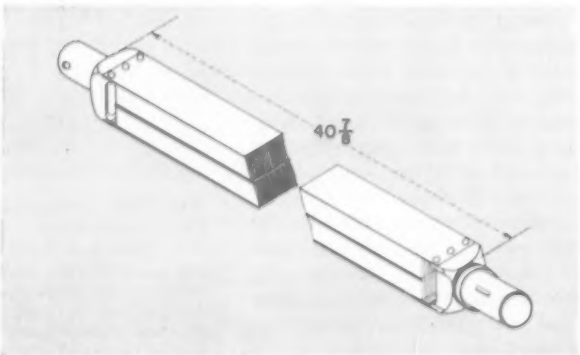


FIG. 2. Plates of fuel element contain cermet core of UO_2 and stainless steel with active height of 36 in.

THE SPERT PROJECT has been established as a part of the AEC's reactor safety program (*1*) for the purpose of conducting studies of heterogeneous, water moderated, enriched-fuel reactors. The experimental findings to date with the unpressurized, water moderated SPERT-I reactor have already been reported (*2, 3*).

SPERT efforts will next be focused on investigations with a high-temperature, high-pressure, water-cooled reactor. Although chronologically it is to be the second SPERT reactor placed in operation, it is referred to as SPERT-III. The reactor will be used to gather basic reactor safety and engineering data during such reactor power excursions as 2 watts to 510 Mw in 0.75 sec. This will be accomplished by rapid insertion into the core of a considerable amount of excess reactivity.

Design Objectives

In designing SPERT-III, the primary objectives have been to provide a reactor in which all phases of safety associated with pressurized water reactors might be investigated. Specifically, these objectives are:

- To provide a facility in which the safety characteristics of pressurized reactors can be conducted under a wide variety of operating conditions of initial power, flow, temperature, pressure, etc. This is meant to include reactor behavior during simulated excursions and oscillations.
- To provide a reactor whose core size and shape can be varied within limits, and whose core is as accessible as possible for instrumentation.
- To provide a reactor in which the hazards associated with such practical problems as the loss-of-flow accident, the cold-water accident, etc., can be investigated without hazard.

To accomplish these objectives, the SPERT-III reactor and associated coolant system are designed to have operational features equal or superior to those of the pressurized-water reactors now proposed. This includes operational temperature and pressure, core-coolant velocity, and maximum heat-transfer rates. The SPERT-III reactor has been designed for the maximum operating conditions of 2,500 psi and 668° F, coolant velocities in the core of about 25 ft/sec, and maximum heat transfer rates of about 750,000 Btu/ft²/hr.

These features, when combined in a single reactor, pose many special problems which extend to the brink of existing technology. To mention only a few of these problems, a reactor vessel design for operation at the required temperature and pressure, and which will withstand the number of thermal cycles required in SPERT-III, has not yet been tested. The temperature imposes a restriction on the fuel materials: fuel assemblies suitable for these temperatures remain untested in an operating reactor. Other special problems include methods for the removal of instrument leads from such a reactor, and the design of rod-drive mechanisms having the desired characteristics yet having a suitable seal.

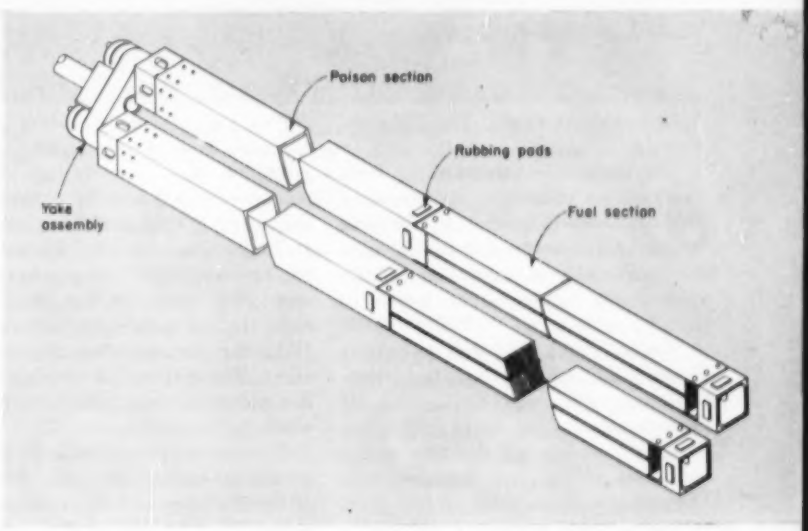


FIG. 3. Box-shaped control rods containing fuel and poison sections are coupled together with yoke assembly so as to be moved by single control rod drive

Summary Description

SPERT-III is a heterogeneous, thermal reactor in which the pressurized-water coolant makes two passes through the core with a maximum flow rate of 20,000 gpm and a heat-removal capacity of up to 60 Mw for periods of about 30 min. Figure 1 presents a cutaway view of the reactor.

Pressure vessel. The vessel has an inside diameter of 4 ft and an over-all height of about 19 ft. The vessel is capable of withstanding shock pressures of short duration to 3,500 psi. The shell of the vessel is of laminated stainless-steel (type 304L) construction 3¼ in. thick.

There are five 1½-in. openings in the vessel head for control-rod drives. Four of the drives position the eight control rods, and the fifth positions the transient rod. In addition, four 6-in. access ports are provided for inserting and removing instrumented fuel assemblies and for disconnecting the control-rod drives.

In the shell of the vessel are six 4-in. access ports, five of which will be used for the removal of instrument leads, and one of which will be used for pressure relief. In addition, six 8-in. exit-coolant-water nozzles penetrate the shell. A modified tee at the bottom of the vessel contains two 16-in. inlet-cooling-water lines.

The outside surface of the vessel is covered by 3 in. of Foamglass insulation. Surrounding the vessel from a point beneath the flange to a point above the bottom tee is a lead gamma shield.

Core structure. The reactor core structure, which consists primarily of the core skirt and the upper and lower grids, is supported from the bottom of the vessel by one of the thermal shields. The upper grid is designed to permit insertion or removal of individual assemblies without removal of the vessel head. The core structure has been designed with the thought in mind that several cores of different shapes and sizes will be placed in the vessel. The reactor-vessel height and control-rod travel is sufficient to accommodate

Sister Reactor—SPERT–II

The SPERT-II reactor will be the third, chronologically, of the SPERT series to be placed in operation. Its primary function will be to study the influence of prompt neutron lifetime on reactor transient behavior and safety. This will be accomplished by using various moderators and reflectors, especially light and heavy water, singly or in combination. The fuel elements contain 4 permanent and 20 removable U-Al fuel plates. With all 24 plates, the assembly will contain 168 gm of U^{235} and a water gap between plates of 1/16 in. By removing every other plate, it will contain 84 gm of U^{235} and water gaps of 3/16 in. The size and configuration of the core can be altered by varying the loading between 28 and 96 fuel elements. The thickness of the reflector can be altered by placing one of several, different-sized, poison-containing shells around the core. Since SPERT-II will not operate at high power levels for extended periods, no heat exchangers have been included in the coolant system.

cores having a maximum active core height of about 42 in. The initial active core height will be 36 in.

The initial core structure has been designed for plate-type, stainless-steel fuel elements (Fig. 2). A cruciform transient rod is located in the geometrical center of the reactor. Fuel-poison type control rods are located in off axis positions.

Positions are provided in the reactor lower grid for a total of sixty fuel assemblies and eight control rods. The fuel assemblies are of two sizes. The smaller ones occupy the four center positions around the transient rod. During studies requiring coolant flow, the unoccupied positions in the lattice will be filled with hollow spacer boxes. Surrounding the core is a ½-in. stainless-steel skirt and 3 thermal shields.

Control rods. The control rods (Fig. 3) are of the fuel-poison type, the fuel being in the lower section and the poison in the upper section. Each pair of rods is joined by a yoke and driven by a single drive mechanism. In addition to controlling the required excess reactivity, this type rod was selected to minimize the number of rods, thereby providing greater flexibility for instrumenting the reactor core. The fuel section consists of 28 fuel plates identical with those in the small fuel assembly.

The material to be used in the poison section has not been resolved. Because of the low integrated flux to which the rods will be subjected, a boron-stainless-steel alloy (enriched in B^{10}) is under consideration.

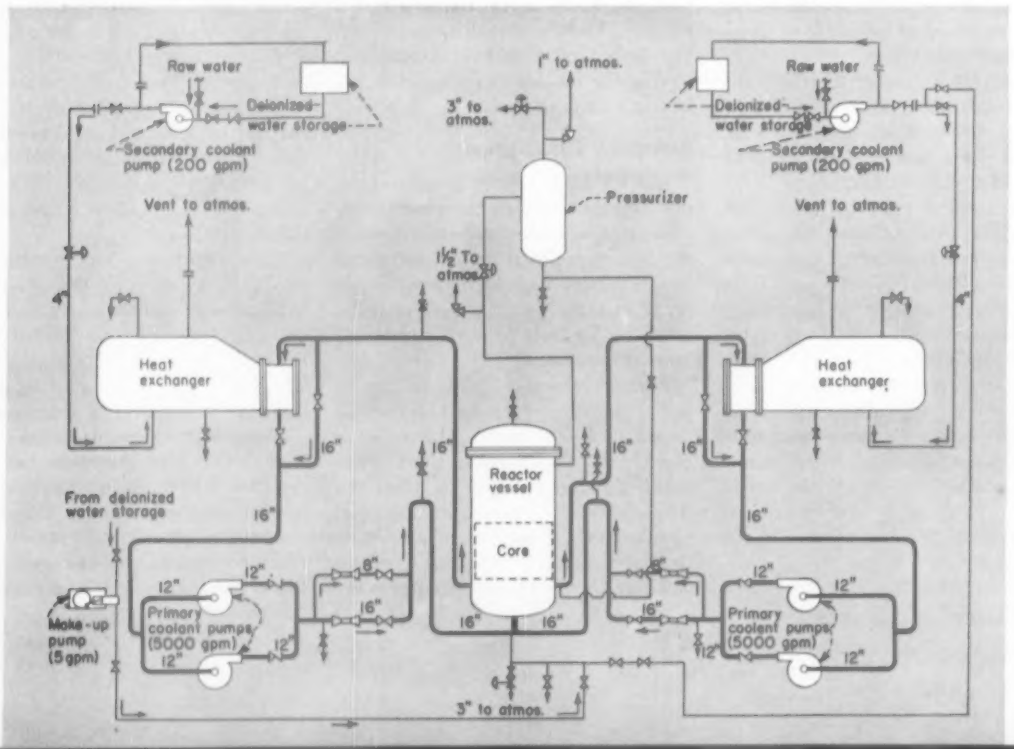
The calculated reactivity worth of the eight control rods is ~21% Δk.

Transient rod. The cruciform transient rod contains poison in the bottom section. Power excursions will be initiated by driving the poison down and out of the core.

Control-rod drives. The control-rod drive assembly consists essentially of a cylinder, piston, shock absorber, drive screw and motor. No direct connection exists between the piston, which is mechanically joined to the control rod, and the drive screw and motor. Air pressure on the bottom side of the piston maintains contact between piston and screw. Air at slightly less pressure, yet sufficient to drive the rod in against reactor pressure, is maintained on the top side of the piston. Rapid insertion of the rods (scram) is accomplished by releasing the air beneath the piston. An air reservoir of sufficient capacity to drive and hold the rod in the down position, under all conditions, is built into the upper cylinder.

Fuel elements. The initial fuel assembly (Fig. 2) is fabricated of stainless-steel consisting essentially of fuel plates, side plates, upper and lower end adapters and a center reinforcing plate. The reinforcing plate has been added to increase the strength of the assembly and minimize vibration of the fuel plates. To reduce pressure differentials in the assemblies, the end adapters have been cut away. The larger of the two types contains 38 fuel

FIG. 4. Schematic flow diagram of SPERT-III systems shows pipe size and coolant flow rate capability of 20,000 gpm



plates with 638 gm of U^{235}. The fuel plate spacing is 0.128 in. Each fuel plate consists of a fully enriched UO_2 and stainless-steel core 0.020 in. thick, clad on each side with 0.005 in. of stainless steel.

Coolant System

The SPERT-III coolant system (Fig. 4) consists of two primary-coolant loops, a pressurizer and the secondary coolant system. The maximum flow rate in each loop is 10,000 gpm. However, the flow can be set as low as 200 gpm. Coolant enters the reactor vessel at the bottom, flows upward through the reactor core, reverses direction and flows downward between the vessel wall and the thermal shields, leaving the vessel near the bottom.

The reactor is located below ground level in a 23-ft deep pit. A second, adjacent pit, separated from the reactor pit by a 3½-ft thick concrete wall, contains all of the coolant system equipment except the heat exchangers (see Fig. 5). They have been located above ground level to permit limited studies using natural convection to circulate the coolant.

Primary-coolant loops. Each primary loop consists of two circulating pumps, two flow tubes, a heat exchanger and the necessary flow-control and check valves. The circulating pumps are canned-motor pumps. Each pump is capable of delivering 5,000 gpm against a head of 328 ft of water The pumps are driven by 500-hp motors. The primary elements for measuring the coolant flow in each loop will be flow tubes. An 8-in. tube will meter the flow rate from 200 to 2,000 gpm, and a 16-in. tube will meter from 1,000 to 10,000 gpm. The flow-control valves will be power-operated, conventional gate valves.

The heat exchangers are of the shell and U-tube type with the primary coolant flowing inside the tubes. The exchangers are horizontally mounted, each having a heat transfer surface area of 1,940 ft². The exchangers are designed for operation as evaporators, the steam thus formed on the secondary or shell side being vented to the atmosphere. The shell side of the exchanger is designed for a maximum operating pressure of 75 psi.

Utilization of the exchangers as evaporators restricts the minimum temperature of the primary coolant leaving the reactor to about 250° F. The heat removal capacity of each heat exchanger is variable from about 1 Mw to 30 Mw depending on the coolant flow rate and the temperature of the coolant entering the exchanger. For operation at primary coolant temperatures below 250° F, the exchangers may be used as liquid-liquid exchangers.

Primary-loop piping is type 304L stainless steel. Stresses in the piping due to thermal expansion are relieved by anchoring the piping near the vessel and permitting the piping and all equipment in each loop to expand in three directions.

Pressurizer. The pressurizer is a 33-in.-i.d. by 13-ft-high stainless-steel-lined tank containing immersion-type electric heaters. The pressure will be automatically controlled by staged operation of the electric heaters. The liquid level is automatically controlled by a 5-gpm makeup pump and a dump valve.

Secondary-coolant system. The secondary water system supplies deionized water to the shell side of the heat exchangers. The secondary system comprises two 250-gpm centrifugal boiler feed pumps and the necessary piping, plus valves, controls, etc., for automatically maintaining the water level in the heat-exchanger shell.

Auxiliary Equipment

The auxiliary equipment associated with SPERT-III includes a raw-water cooling system, a water treating system, two compressed air systems, and an emergency power supply.

High purity deionized water having a resistivity of ~1 megohm-cm will be used in both the primary and the secondary coolant systems.

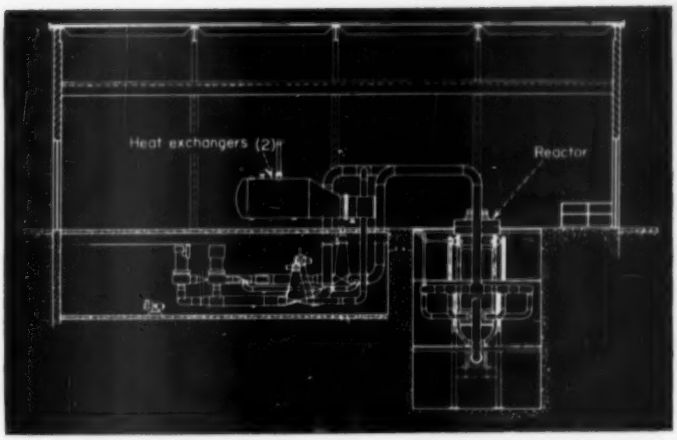


FIG. 5. SPERT-III building is of concrete block. Hot storage facilities include eight dry-storage holes in concrete floor and 16-ft deep water-filled pit (far right)

Instrumentation

Because 3,000 ft separate the reactor and the control center, electronic transmission has been specified for all signals transmitted to the control center. The signals will be transmitted via multiconductor or coaxial cable, as required, which will be laid on the surface of the ground. Cables transmitting power signals will be separated by a distance of about 15 ft from cables transmitting instrument signals. In the interest of obtaining accurate pressure indications, more than one transmitter has been provided for each application because of the wide range of operating pressures.

The control-rod-drive system is composed of an a-c drive motor, a mechanical drive continuously variable in speed, selsyn transmitter and four selsyn receivers with gearmotors and brakes. The principal features incorporated in the design are: (a) The system will provide for individual or synchronized operation of all control rods. (b) The system will provide for continuous, variable-speed operation of the control rods, both in and out, from 1 in./min to 50 in./min. This range of drive speeds provides a reactivity addition of from about 0.58% Δk/min to 29% Δk/min.

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2. W. E. Nyer, et al. Transient experiments with the SPERT-I reactor, NUCLEONICS **14**, No. 6, 44 (1956)
3. S. G. Forbes, et al. Instability in SPERT-I, NUCLEONICS **15**, No. 1, 41 (1957)

1 CARRYING Zr SCRAP. Employees wear asbestos helmet, gloves and leggings and chrome-leather apron. Storage pail is shown being carried in yoke from metal locker. Scrap is removed daily from machine shop and stored under water in 5-gal pails

2 LOADING INCINERATOR. Pail is supported over incinerator by yoke, extension handle is fitted, and yoke is rotated to dump contents. Scrap is burned in quantities of 35–400 lb

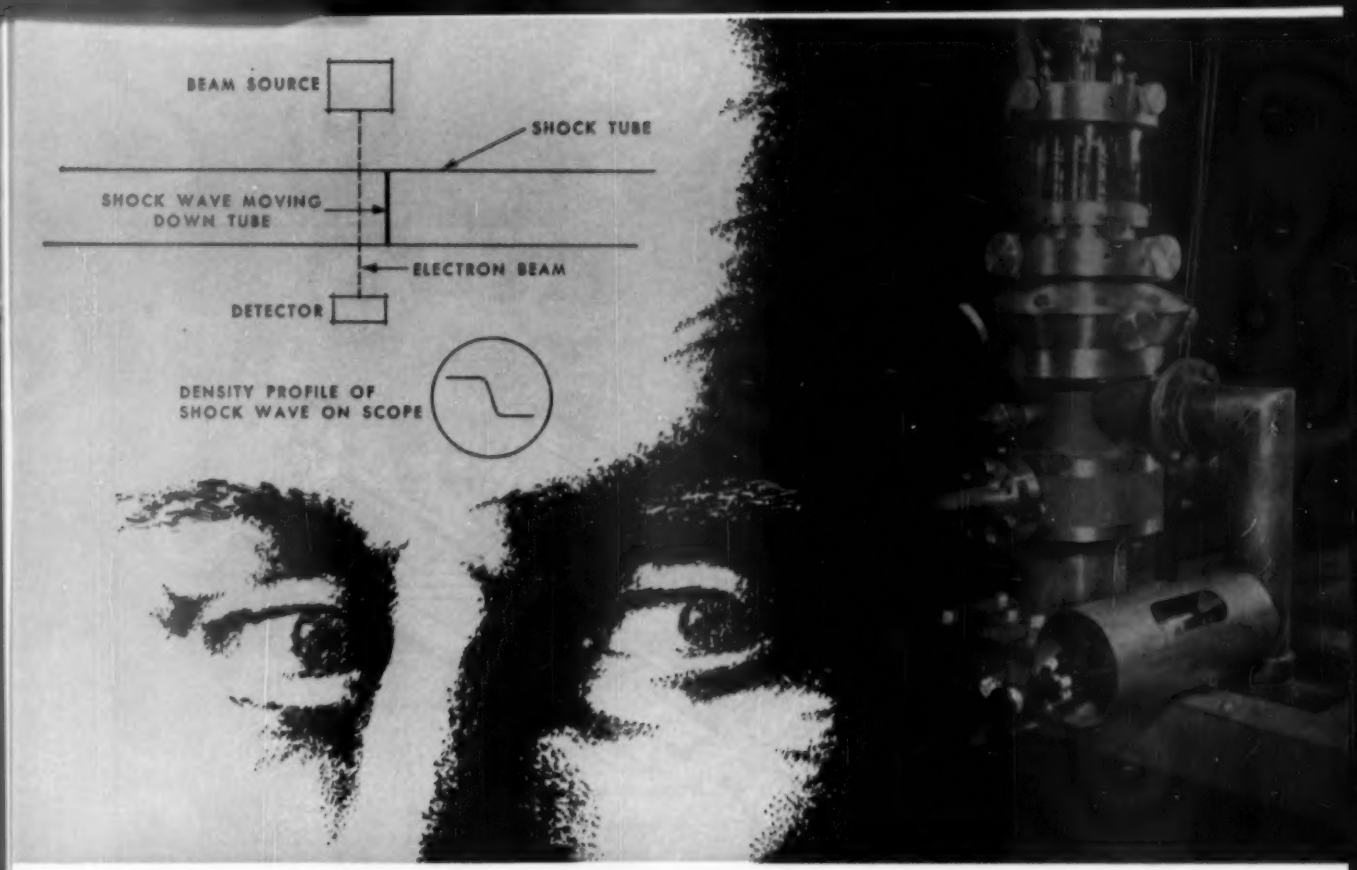
How One Company Avoids Zirconium Pyrophoricity Hazard

By EDWARD W. KRANS
Combustion Engineering, Inc.
Windsor, Connecticut

FIRES AND EXPLOSIONS have occurred spontaneously in zirconium scrap under storage conditions (NU, Dec. '56, p. 28). Combustion Engineering, which handles about 1,500 lb of zirconium turnings and fines per month, has used the procedure shown here without incident since last November. Basically, we convert pyrophoric Zr to nonpyrophoric ZrO_2 for safe storage.

3 LIGHTING FIRE. Gasoline-soaked rag, tied to 20-ft fuse, is placed on scrap. If necessary, 6-ft pole is used to insure good contact between rag ball and scrap

4 Zr SCRAP BURNS TO SAFE ZrO_2. Typical view at peak of burning. When combustion dies down to steady glow, lid is placed on incinerator. Oxide is cooled overnight



new technique helps Los Alamos scientists take a sharp look at shock waves

The electron densitometer shown above was designed and built at Los Alamos Scientific Laboratory to study the structure of shock waves and to investigate the fast reactions associated with strong shock and detonation waves. This instrument provides space resolution of less than 0.2 mean free path under normal operating conditions. It is believed that this is the first application of electron beam techniques to the direct measurement of transient flow phenomena.

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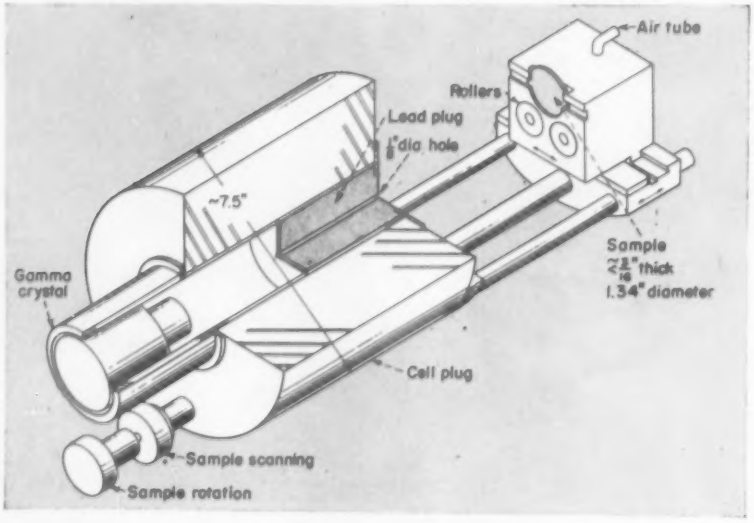


FIG. 1. Location of fission products and consequently of U^{235} burnup in irradiated fuel is accomplished with this device designed and constructed by R. S. Paul of the General Electric Fuels Preparation Dept., Richland, Washington. Scanner accepts thin wafers cut from fuel, permits moving them past thin hole in lead collimator. Scintillation crystal detects fission-product gammas. Instrument is mounted on plug that fits hole in wall of hot cell so that it can be removed for alteration or maintenance. Wafers are inserted by master-slave manipulators

Wafer Scanner Locates U^{235} Burnup in Fuel

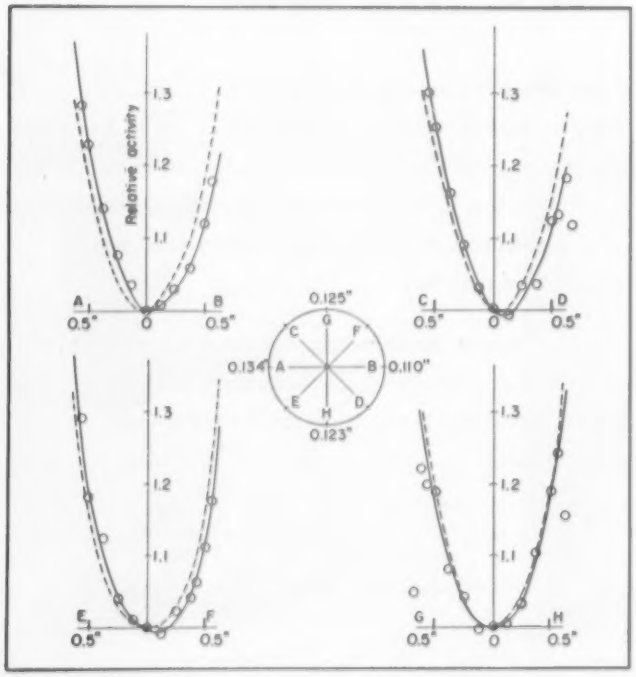


FIG. 2. Gamma counts on four diameters are measured with pulse-height analyzer (solid curves) and corrected for variations in sample thickness (dotted curves). Resolution in wafer sample is ~⅛ in. Skew in curve, which is sometimes extreme, indicates influence of nearness to control rods, misalignment of fuel in its channel, etc. These curves represent gammas of energy $\gtrsim$ 0.9 Mev from sample irradiated ~2 months, then aged 57 days. Numbers at edge of circle at center are measured thicknesses

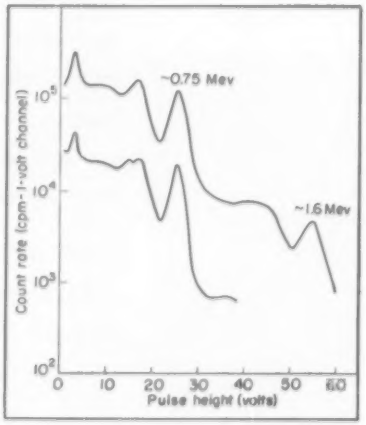
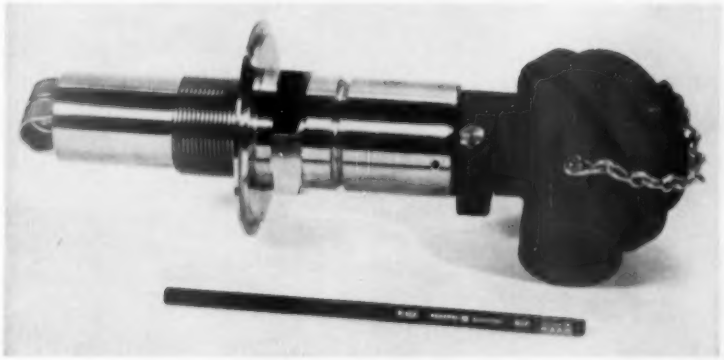


FIG. 3. Differential pulse-height spectrum of upper curve is from counting of sample used for Fig. 2. Clean peak at 1.6 Mev from La^{140} permits absolute determination of this activity. Lower curve, taken 23 days later, shows disappearance of 40.2-hr La^{140} activity



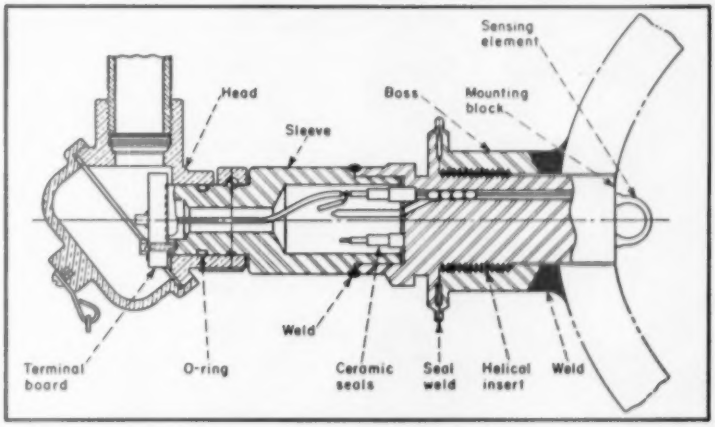


FIG. 1. Resistance temperature detector and its construction

Resistance Thermometer for Nuclear-Reactor Service

By F. RALPH SIAS
General Electric Company
West Lynn, Massachusetts

A resistance temperature detector (RTD) has been designed for the Submarine Advanced Reactor* that will more than fulfill operational requirements. It has very fast response and high power-dissipation ability under flow conditions. It can be adjusted to high precision and will maintain this adjustment for long periods of time in a radiation field.

Although designed for operation below 3,000 psi on the sensing element, it has withstood testing well above 5,000 psi. It is sufficiently rugged to withstand extreme shock and vibration.

The accuracy of temperature measurement determines whether a power plant operates efficiently—close to the upper boundaries of mechanical strength and close to critical pressures—or with large safety margins. Various systems are available for temperature measurement.

For application in a nuclear reactor, fluid-filled systems are excluded because the connecting piping would make a passage for the escape of radioactive materials. Thermocouples can be made to give reasonably good accuracy. But the systems are complicated by cold-junction compensation devices, and the signal power available is small.

The electrical-resistance thermometer has long been the standard for precision thermometry. Much more power can be used in the measurement

* The Submarine Advanced Reactor is a pressurized-water type being developed at Knolls Atomic Power Laboratory, Schenectady, N. Y.

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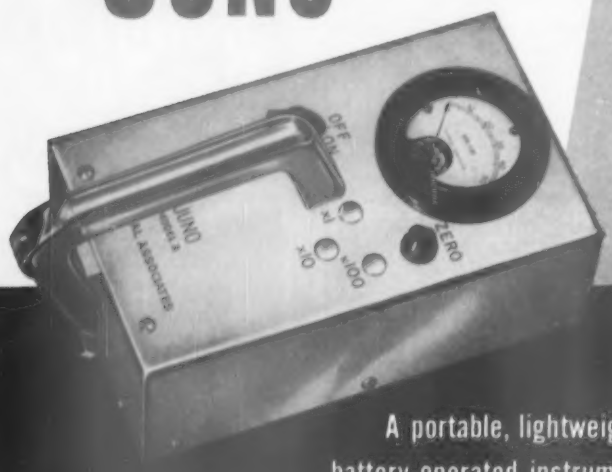

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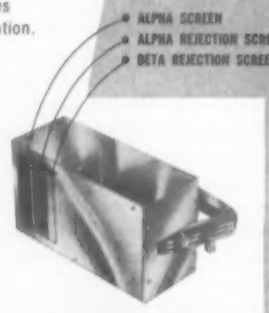

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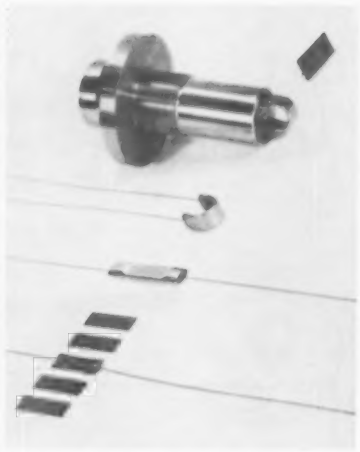


FIG. 2. Sensing-element sandwich is enclosed in U-shaped stainless-steel tube

circuits than in a thermocouple system, and no cold junction compensation is required. It was therefore selected for this critical measurement task.

Specifications

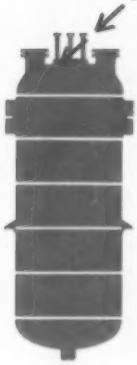
If water is used as the heat-exchange medium in a reactor, the critical pressure and temperature are 3,184 lb/in² and 705° F. These were used as preliminary design goals. Additional requirements include a flow rate of 45 ft/sec and a response time of 1.0 sec (63%). Devices used near a reactor are also subject to a radiation field, the intensity of which depends on the location of the device. For this application a fast-neutron flux of 1×10^8 n/cm²/sec, thermal of 5×10^8 n/cm²/sec and gamma of 200 r/hr were selected as upper limits. Desired life is 40,000 hr.

The ambient air temperature is 70° C. Navy shock and vibration tests are required. Also, equipment attached to submarine piping must be strong enough to be used as a step for maintenance people because of the extremely crowded conditions.

Design

The design of the RTD is shown in Fig. 1.

Sensing element. There are always conflicting requirements for an RTD sensing element. Fast response demands low thermal capacity and high thermal conductivity. Low self-heat demands large areas. Strength calls for thick protecting walls. Good electrical stability requires that electrical insulation be good, usually with low thermal conductivity. Soft wirelike



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platinum must be mounted so as to be strain-free with attendant poor thermal contact. These qualities must be balanced in a good RTD to best fulfill the design goals.

First, of course, are its electrical characteristics—its resistance-temperature curve. This must be precisely established and stable over a long period of time. Tungsten offers advantages as the resistance material.* Stabilities obtained are as great as those of platinum, and, in addition, precise control of temperature coefficient and resistance is more easily obtained.

In addition to temperature stability, the RTD must be stable under a radiation field for a number of years. Nine tungsten units were irradiated in the Instrument Tunnel at the Brookhaven National Laboratory for 40 hr to a radiation field that gave an integrated flux equivalent to 40,000 hr of operation. When compared with other units as controls, there were no significant changes due to radiation.

Fast response requires that the sensing resistance be in as intimate contact as possible with the medium whose temperature is to be measured. In addition, it must withstand very high pressures. The construction chosen is shown by Fig. 2. The winding itself is wound on three notched mica cards, and nichrome leads are attached. Nichrome is used because it has a very low thermal EMF against tungsten over a very wide range. Two additional mica strips are placed on either side of the winding to form a sandwich. Several 0.0025-in. mica strips are used instead of single thicker ones to facilitate the bending operation.

The sandwich is then slipped into a flattened stainless-steel tube and the whole bent in a die to the "U" shape shown. This operation stresses the outside wall of the "U" beyond the elastic limit and leaves the walls of the tube pressing on the mica sandwich with considerable pressure for best thermal contact.

The sensing element is next inserted into the machined groove in the nose of the mounting block and brazed with a gold-nickel alloy. This method of mounting leaves the tube supported on both the inside and outside. When pressure is applied to the sensing element, it does not put the gold solder in tension. The remaining space in the

* F. R. Sias, J. R. Macintyre, A. Hansen, Jr., *Trans. Am. Inst. Elec. Engrs., Part 1, Com. and Electronics* **73**, 66 (1954).

MEMORANDUM:

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sensing element, around the leads, is filled with alumina powder, packed as tightly as possible. Thus external pressure cannot distort the protecting tube but, instead, tends only to increase the pressure on the sensing element and improve its response characteristics.

If the sensing winding were made of platinum or other soft metal, the pressure on it would seriously strain and distort the wire, thus changing its resistance characteristic. Even if the adjustment were perfect before forming and stable after forming, it would have a significantly different value, and the amount of change during forming could not easily be predicted. When tungsten is used, its high strength allows little change in resistance during the forming process. In addition, since the resistance adjustment is made chemically,* any change that does occur is corrected. Tests made on the completed RTD show that the temporary change in resistance due to external pressure is negligible.

Tungsten has a further valuable advantage. When an RTD is used for indicating or controlling temperature, it is often used in a bridge circuit that is balanced at one particular temperature and at any other temperature is unbalanced. The voltage output of this bridge, for a uniform change in resistance of the RTD, is nonlinear. It is desirable for many applications to have an output voltage that is linear with temperature. This is possible with a tungsten RTD, for the bridge and RTD curvatures are opposite and compensate each other when the correct values of bridge resistors are chosen. The linearity can be made better than 1° F over a 700° F range and to better than ¼° F over most of the range.

Mounting block. The mounting block is machined for two sensing elements so that two separate temperature measurements or a spare element can be provided with a single penetration of the high-pressure piping. This penetration is made by welding a boss to the pipe. This boss is threaded internally oversize. A helical coil of hard-drawn diamond-shaped wire is screwed into the thread to serve as the inner thread surface of the nut. It reduces the possibility that thread galling will prevent the removal of the RTD.

The thread provides the strength to withstand the internal pressure in the

* *Ibid.*

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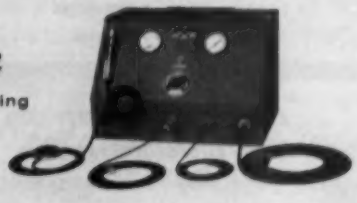

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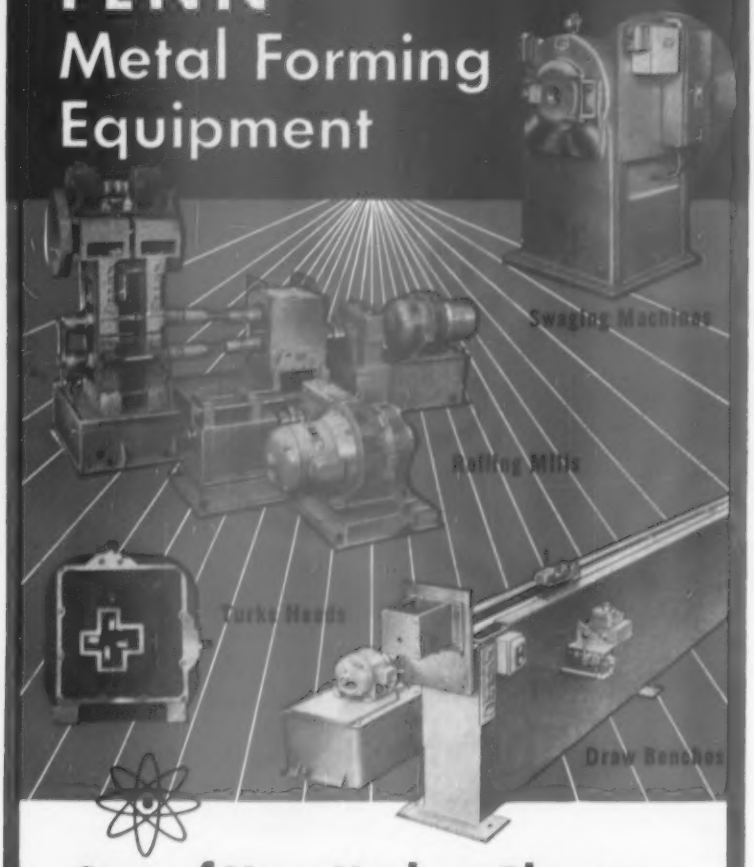

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pipe. To prevent leakage, a seal weld is made at the flange.

The mounting block also contains passages for the leads. Ceramic high-temperature hermetic seals are silver-brazed directly to this part. An evacuating tube for each sensing element allows powdered alumina to be introduced and packed as much as possible to prevent movement of the leads due to vibration and shock. Helium is then added at a pressure slightly higher than atmospheric pressure. The sleeve is then installed and welded in place.

Head. The head must be waterproof. It is also desirable to allow the conduit fitting to be located in any direction. Therefore, the head is mounted on the sleeve with an O-ring seal and clamp to secure it in the desired position. The terminal board is mounted directly on the sleeve to allow rotation of the head without twisting the leads. Before assembly of the terminal board, the cavity in the sleeve is filled as completely as possible with coarse alumina to prevent failure of the leads due to shock and vibration.

Testing

The RTD was tested for response time, self-heating and pressure effects.

Response time. Response-time tests were made by inserting the RTD in a pipe in which water at about room temperature could be maintained at flows up to 50 ft/sec. Water was first drained from the pipe and the temperature of the RTD raised to about 100° C. A quick-opening valve allowed a full flow of water to enter the pipe, thus making a step change in temperature.

The RTD was connected to a Mueller bridge balanced for a 63% change in temperature. It was excited with 60-cycle a-c, and the output was applied to a recorder. The response time was taken as the time between the beginning of the change in bridge balance and the balance point. At a flow of 30 ft/sec, the response was 0.4 sec, and at 5 ft/sec, it was 0.6 sec.

Self-heat. This test was made in the same apparatus as used for response time. Flow was set at a desired rate, and the RTD resistance was measured with negligible power applied to the bridge. The power was then raised, and the change in resistance was converted to self-heat temperature rise.

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nents of the RTD have been pressure-tested separately. This has been done on a dead-weight tester, failure being indicated when an actual leak occurred, or where it became impossible to increase the pressure further owing to the expansion of the system.

The sensing element itself was tested to 5,500 lb/in^2 without failure. The only visible effect was a slight reforming of the element base where it was brazed into the mounting block. No significant changes in resistance due to pressure were noted. Insulation resistance remained high.

Although the hermetic seals are not normally required to withstand high pressure, in the event of a failure of the sensing element they would be subjected to full working pressure. A number of seals were tested up to 10,000 psi, the minimum failure pressure recorded being 7,000 psi.

A special test model of the mounting block and boss was made to test the effectiveness of the Helicoil thread and seal-weld design. The seal weld showed no sign of failure up to 9,000 psi. The thread began to give at about 8,500 psi.

* * *

This article is based on a paper presented at the 2nd Nuclear Engineering and Science Conference in Philadelphia, March, 1957, and sponsored by the American Institute of Electrical Engineers.

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NUCLEONICS

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Well-Bottom Container Improves Gamma Counting

By ARTHUR F. DRATZ
Veterans Administration Hospital, Atlanta, Georgia

A special sample container (Fig. 1), somewhat like a Marinelli beaker (*1*), permits exposure of the top and sides of a sodium-iodide scintillation crystal to the gammas from a radioactive solution. Its improved counting rates permit a direct, relatively rapid assay of large aliquots of dilute Co^{60} solution. With narrow-window counting we have realized ~9% resolution of both Co^{60} peaks in counting a liter containing 2.5 μc. With a slightly wider window or integral-bias discrimination our data show that 3% standard error in counting 1 liter of solution containing 0.005 μc can be attained in 12–20 min.

Such solutions are frequently encountered in a useful clinical test for the diagnosis of pernicious anemia. For clinical purposes, a counting system that permits assay of one liter of a 5×10^{-6}-μc/ml Co^{60} urine to a standard error of 3–5% in a reasonably short time is quite satisfactory (*2*). Our apparatus meets these criteria.

Apparatus

The container is as shown in Fig. 1. A volume of 650 ml will fill it to the top of the well. Each additional 350 ml will raise the fluid level approximately 1 in. A sheet of Parafilm, held in place by rubber bands, provides a convenient cover.

A minimum clearance is left between the top of the crystal can and the surface of the well. Felt strips taped to the inner vertical surfaces of the lead shield prevent lateral movement of the sample container and possible damage to the crystal.

Results

Operating the photomultiplier at 850 volts and using a differential pulse-height analyzer with a 3-volt window, the energy spectrum produced by 1 liter of a Co^{60} solution (~2.5 μc) was determined. The 1.17- and 1.33-Mev Co^{60} peaks were clearly resolved with resolutions of ~9 and 8%,* respectively. Higher counting rates were obtained from the same Co^{60} solution by reducing the photomultiplier voltage to 770 and increasing the window to 6 volts (Fig. 2). These conditions correspond approximately to a 10-volt window at the previous voltage of 850. The maximum counting rate observed in Fig. 2 (1.33-Mev peak) for 2.5 μc of Co^{60} is 54,700 cpm over a background of 45 cpm. From this data it can be calculated that under these conditions a liter of solution containing 0.005 μc of Co^{60} can be counted to a standard error of 3% in about 19 min.

An integral-bias counting system rejecting all pulses below the bias setting was employed in several experiments. A maximum sample-to-background count ratio of approximately 10 to 1 was obtained at a discriminator setting

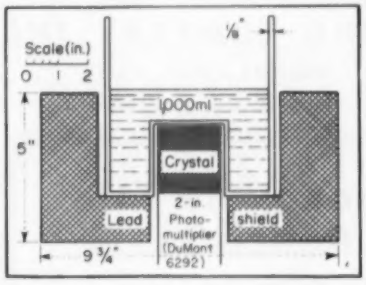


FIG. 1. Canned 1¾ × 2-in. NaI crystal fits inside bottom well of Plexiglas container

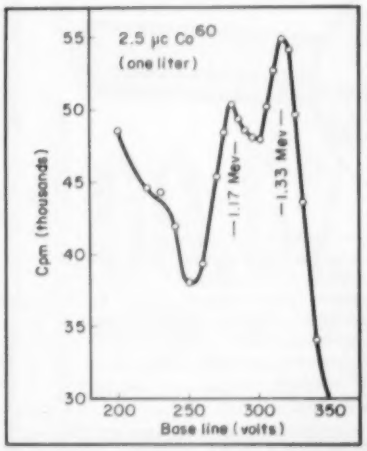
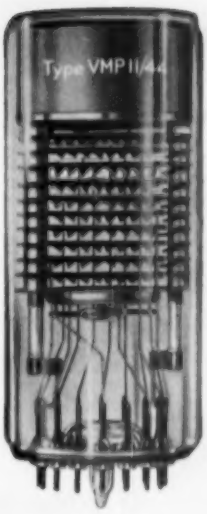


FIG. 2. Six-volt window and photomultiplier potential of 770 volts produces 54,700 cpm from 2.5 μc of Co^{60} at 1.33-Mev peak. Background there is 45 cpm

* Per cent resolution equals width of peak in volts at half-maximum counting rate divided by the base-line voltage at the peak times 100. Half-maximum counting rate is halfway between top of peak and base of peak.



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Minimum overall sensitivity at 160 v per stage	200 A/L
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Maximum dark current at 200 A/L	0.1 μA
Anode capacity	8 ppf
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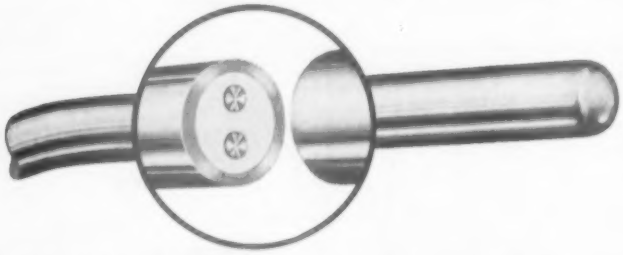

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Write for Bulletin 305-K.

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Counting Rates*

Volume (ml)	Background (cpm)	Co⁶⁰ counting rates (corrected) (cpm)	(cpm/ml)
650	286	1,964	3.02
1,000	268	2,711	2.71
1,650	244	3,343	2.03

* These rates came from integral-bias-discriminator counting of various volumes of a 5×10^{-4}-μc/ml Co^{60} solution.

of 45 volts. Using this setting further data were obtained by counting 0.2 μc of Co^{60} in various volumes of water. Backgrounds were determined in a similar manner. Both the background and Co^{60} counting rates decrease with increasing volume. By converting the equations for the linear portions of these curves from absolute to relative terms we get the following relationships

$$B_x = B_1(1.12 - 0.12x) \quad (1)$$
$$C_1 = C_x/(1.44 - 0.44x) \quad (2)$$

Here x = volume in liters, B_x = background cpm in x liters of water, B_1 = background cpm in 1 l of water, C_x = Co^{60} cpm in x liters of sample, C_1 = Co^{60} cpm if x liters of sample were concentrated (or diluted) to a 1-l volume.

If different volumes (0.7–1.7 l) of several Co^{60} samples are to be assayed, these equations are quite useful in reducing the number of determinations required. Using Eq. 1 the background counting rate for any volume up to 1.7 liters can be calculated if the background rate in any known volume is determined. By applying Eq. 2, each of the sample counting rates (corrected for background) can be compared readily with that obtained for a single Co^{60} standard counted in a 1-l volume.

Improving Sensitivity

To obtain the maximum counting rate, particularly in the assay of dilute Co^{60} solutions, it is advantageous to count the largest possible sample volume. Although the specific counting rate (cpm/ml) of sample decreases with increasing volume, the increased amount of Co^{60} present in these larger sample aliquots produces a net increase in the counting rate. This is illustrated by the data in the table obtained by counting various aliquots of a Co^{60} solution of $\sim 5 \times 10^{-5}$ μc/ml.

A liter of this solution gave 2,711 cpm above background. Since 650 ml fills the plastic container to the top of the well, it can be predicted, by subtracting

the 650-ml counts from the 1,650-ml counts, that only 1,379 cpm could be obtained if a liter of this Co^{60} solution were counted in a flat-bottomed vessel of the same diameter placed on top of the crystal. This is only about half the counting rate observed using the well-bottomed containers. Many laboratories use flat-bottomed vessels for the assay of liter volumes of Co^{60} solutions. Since small-diameter (4 in.) vessels are often used, and since the sides of the crystal are usually shielded with lead, even lower counting rates are obtained.

From counting rates observed with the well-bottomed containers and an integral-bias counting system it can be calculated that a liter of solution containing 0.005 μc of Co^{60} can be counted to a standard error of 3% in 12–17 min. In these experiments no attempt was made to determine the absolute Co^{60} concentrations in the solutions used, which were prepared from various lots of commercially available Co^{60}-labeled vitamin B_{12}.

This counting well can be improved in several ways: The lead shield was cast in this laboratory from generally available lead; if selected lead with a low level of natural radioactivity were used, lower background counting rates can be obtained. The size of the Plexiglas containers was largely determined by the stock sizes of Plexiglas pipe available commercially. A slightly larger well would permit the use of a canned 2 × 2-in. sodium-iodide crystal and result in higher counting rates. If sample volumes greater than 0.8 l are usually available for assay, improved counting rates also can be obtained by increasing the overall diameter of the containers since this would permit a greater portion of the solution to surround the crystal.

The plastic containers were fabricated locally at a cost of $8.00 each. However, less expensive materials could be used. We have found that the containers can be decontaminated easily by a simple brushing with a commercial detergent solution containing a chelating agent.

* * *

The author wishes to acknowledge with thanks the many valuable suggestions of Robert H. Rohrer, Department of Physics, Emory University. The author also wishes to thank Walter H. Cargill and James C. Coberly of this laboratory for their evaluation of the clinical applicability of this counting technique.

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2. J. C. Coberly, private communication

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NUCLEAR ENGINEERING NOTES

HRT Uses Oxygen for Pressurizer

Design plans for the Homogeneous Reactor Test (HRT) at Oak Ridge call for a system operating pressure of 2,000 psig. The high pressure is necessary to prevent the boiling of the 300° C water in the core and to reduce the volume occupied by radiolytic gas in both the core and blanket. One of the problems facing the HRT is that of designing a pressurizer system capable of maintaining the 2,000 psig static pressure. An additional requirement of such a system is that it must provide a surge volume large enough (about 10 liters) to handle the fluid expansion during sudden power excursions without excessive pressure increase.

The simplest approach (and one which ORNL is considering) is to pressurize the free surface of the water with a suitable gas. The gas volume would be large enough to give adequate surge protection. The next question is: of all the gases available which is the most suitable? A recent study of this point for the AEC by Arthur D. Little, Inc. came up with a surprising answer—*oxygen*.

The study concluded that oxygen was the best gas for HRT pressurization because it is:

- chemically compatible with both the core and blanket materials.
- readily available commercially or easily produced at the plant site if desired.
- safely handled in commercially available equipment.
- easily disposed of by burning with ordinary hydrogen.

Since one of the prominent hazards of the HRT is the possibility of a hydrogen explosion resulting from the buildup of the radiolytic gases D_2 and O_2, one might think that oxygen would be at the bottom of the list when it came to selecting a pressurizing gas. The investigators, themselves, admit that at these temperatures and pressures not much is known about the explosive limits for D_2-O_2 mixtures. However they feel that the D_2 concentration in the gas can be kept at such a low value that the pressurizer vessel can be built to withstand any explosion that might occur. Under normal operating conditions the D_2 concentration would be held below 0.75%. Under emergency circumstances the concentration is not expected to rise above 3.25%. If the D_2 were detonated at this concentration the peak pressure would be about 9,500 psi. It was recommended that the pressurizer be designed for a static pressure of 6,500 psi. This would give a large enough safety factor to handle the 9,500-psi pressure pulse that might result from a detonation.

Borax-4 Uses UO_2-ThO_2 Pellets

For the first time, Argonne National lab is using ceramic pellets of urania-thoria as fuel constituents in a nuclear reactor. The pellets are now being used in a Borax series experimental reactor at the National Reactor Testing Station.

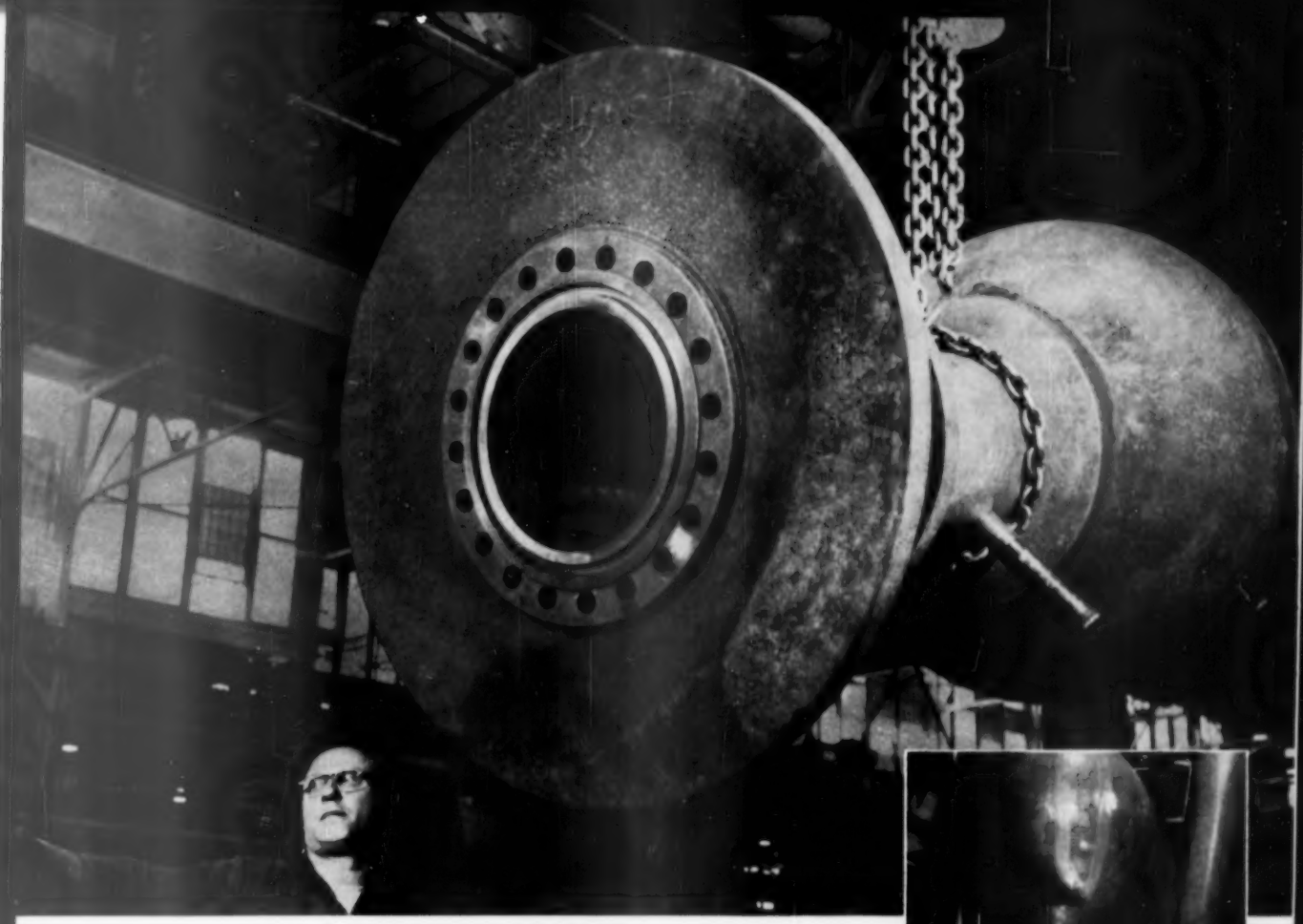
The feasibility of using ceramic fuels in a boiling water reactor is discussed in a paper by Hoenig, Handwerk, Kittel, and Breden presented at the annual meeting of the American Ceramic Society at Dallas, Texas. Results were given of the preliminary studies of the effects of irradiation on the uranium and thorium oxides.

The ceramic specimens were first tested both with and without cladding. Aluminum-nickel alloy, stainless steel, and Zircaloy-2 were used on the clad specimens. The pellets were put in water and in sodium-potassium (NaK) and irradiated. They showed good resistance to corrosion in either water or NaK and only slight distortion under irradiation.

The results of the tests indicated that the Al-Ni cladding was the most satisfactory, and it's been used in the fuel of Borax-4. The Borax-4, now in operation, was designed to test, among other things, the operation of a boiling water reactor under more extreme heat transfer conditions than previous Borax reactors. Initial tests have shown that the ceramic pellets perform satisfactorily at quite high levels of power.

Homogeneous Research Reactor

Atomics International has recently obtained AEC permission to construct a 5-watt aqueous homogeneous research reactor. The fully enriched uranyl sulfate fuel solution is contained in a spherical, stainless steel vessel surrounded by 6 in. of lead that serves as both reflector and primary shield. The facility is designed to provide a low-cost, easily operated reactor for use by industrial labs, educational institutions and research centers.



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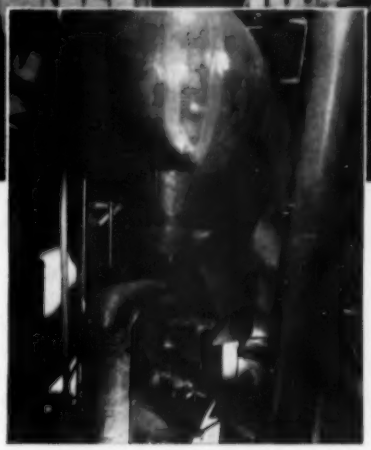

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Report on the Venice Conference

Thermonuclear Research the World Around

By L. REIFFEL *Armour Research Foundation, Chicago, Illinois*

The Third International Conference on Ionization Phenomena in Gases, originally devoted to the classical problems of gas discharge physics, was this year suddenly over-run by the new breed of researchers working on the control of thermonuclear reactions. Approximately one third of the June conference held in Venice was given over to papers discussing controlled fusion theory and experiment. This was the first time that the United States and Great Britain have entered into unclassified discussions in this area with other nations since Igor Kurchatov originally started the ball rolling by revealing details of the Russian program at Harwell, April a year ago. (NU, June '56, p. 36.)

The conference was also noteworthy in that it brought to light the great international interest that is springing up, especially in Europe, in the subject of controlled fusion research. The position of this research from the world-wide point of view can be summed up by saying that so far no one seems to have achieved a genuine controlled thermonuclear reaction but experimental and theoretical results are increasingly encouraging.

Fusion Theory

The four sessions of theoretical papers on thermonucleonics fell into two general classes. One group was concerned with the properties of plasma, either fully or partially ionized, and attacked the very difficult questions of computing plasma conductivity and other properties, especially those needed for purposes of temperature measurement. It is clear that both microwave methods and optical methods still leave much to be desired as techniques for measuring properties of plasmas achieved in experimental apparatus.

A second grouping of the theoretical papers concerned the stability of the pinch effect and the motion of ions across magnetic fields. A. Schlüter and R. Lüst at Gottingen (Germany) presented an interesting idea for achieving high plasma temperatures by means of magnetic cycling in a conducting gas. The magnetic field is first used to increase the particle velocity in a plane perpendicular to the field. After sufficient time is allowed for collisions to transfer some of this increased energy into components parallel to the field, the magnetic field is reduced. This does not affect the gain in energy due to the velocity components parallel to the field so that the gas is left hotter than it was originally. The heating process can be done cyclically and theoretically leads to very high temperatures. The same process can be applied in a slightly different way using a beam of particles which is accelerated and injected into a magnetic field configuration capable of confining the particles until randomization of the velocities can occur.

British Pinch-Effect Apparatus*

	Original apparatus	*Revisions after Kurchatov speech*	*New apparatus*
Total capacity (microfarads)	113	162	100
Max. voltage (kilovolts)	10	10	30
Energy (joules $\times 10^3$)	5.6	8.1	45
Inductance (henries $\times 10^{-9}$)	13	10	6 (calc)
Short circuit current (amp $\times 10^6$)	0.8	1.7	4
Rate of rise of current (amp/sec)	7×10^{11}	10^{12}	5×10^{12}
Quarter cycle time (microseconds)	1.9	2.0	1.2
Number of spark gaps	10	144	200
Breakdown time of spark gaps (microseconds)	<0.05	<0.01	<0.01

* From presentation by S. C. Curran based on work at Aldermaston.

M. Rosenbluth of General Atomics (U. S. A.) and R. J. Tayler of Harwell (England) both described theoretical work on the pinch effect with axial magnetic field stabilization. They showed that a magnetic field applied along the axis of a linear pinch can result in a high degree of stability. Rosenbluth pointed out that if one considers the difference in magnetic field strength in the region outside and inside the ionized gas, then it appears that a linear pinch which has infinite conductivity and is surrounded by an external coaxial conducting wall (for the return current) will be absolutely stable. One difficulty introduced by the use of an axial field is that it makes the pinching discharge much "stiffer" and, thereby, reduces the achievable temperature.

Fusion Experiments

The greatest excitement was aroused by two hurriedly scheduled brief descriptions of recent work in Sweden and England.

K. Siegbahn of Uppsala (Sweden) presented a detailed description of the apparatus he is using to study pinch effect (the story of some of his work broke in the newspapers before the conference). His apparatus consists of 120 0.5-μfd condensers at 50 kv. He has achieved an inductance of 5×10^{-9} henries and usually works at voltages between 20 and 30 kv. The ca-

pacitors are simply arranged on a table around a circle about 6 ft in diameter and the discharge tube is positioned at the center of the circle. The pinch tube itself is 60 cm in length and 28 cm in diameter and is switched onto the capacitors by means of a single triggered spark gap.

A key point in Siegbahn's apparatus seems to be that he has covered his electrodes in the pinch tube (there is one flat electrode at each end) with porcelain discs. This artifice apparently avoids the sputtering which has plagued other experimenters and allows the maintenance of relatively pure gas in the tube. Neutron production in the pinch is sensitive to impurities and the tube is precleaned by running a low current discharge at higher than normal operating voltage prior to starting the pinch experiments.

Siegbahn gets the neutrons usually in the second and third contraction (or bounce) of the pinch and interestingly enough occasionally observes neutrons in the first and second bounce or sometimes even in all three bounces. (Three bounces seems to be the standard number in a linear pinch.) The number of neutrons obtained in a single shot is $\sim 10^7$ and results from a current of 300,000 amp applied with a 3-μsec rise time. He has confirmed the neutron production by activating silver foils and has achieved levels of about 100 cps in such foils. Since the usual pinch experiments do not yield neutrons in the first contraction it was suggested that Siegbahn has some assymmetrical property built into his tube which produces neutrons by an acceleration mechanism.

Siegbahn's brief report was followed by an unscheduled discussion by S. C. Curran and his associates on their pinch effect work at Aldermaston (England). He mentioned that their group had gotten interested in the pinch effect some two years ago and have so far built and operated two sets of equipment with a third apparatus now under construction. The second apparatus was actually a modification of their first design after they heard the now-famous Kurchatov speech. The table, gives the significant parameters of all three of Curran's machines. The big machine has not yet gone into operation. With his second machine a 15-cm-diameter by 28-cm-long quartz tube was used for the discharge and facilities were available to apply a longitudinal field up to 1,600 gauss. In all cases the capacitors are connected to the discharge tube by coaxial cable and the charge on each capacitor is applied to the discharge through individual, but simultaneously triggered, spark gaps. This group reports that it is "easy to get neutrons" and they suggest that impurities are not as important as other groups seem to feel they are. With their 162-μfd machine they obtained $\sim 10^8$ neutrons and found they could tolerate as much as 1 or 2% nitrogen in the deuterium without much change in the neutron yield. They observed neutrons on every discharge. With 3–6% nitrogen, they found the neutron yield was reduced about a factor of 10, but they still get neutrons on every shot. With 7–11% impurity, they get neutrons in about 30% of their shots, but the yield was down 20 to 50 times. When they applied a longitudinal magnetic field of 1,000 gauss, the yield of neutrons dropped a factor of 10. At 1,600 gauss they get an additional factor of 2 reduction in the yield. This behavior in a magnetic field combined with the relative insensitivity of neutron production to impurities indicates that a different mechanism must be operating from that observed at Livermore.

The English group also looked for high voltage X-rays from light-H pinches but were unable to observe any. They concluded that the X-ray to neutron ratio in their D pinches is $<10^{-3}$. They find that the neutrons in their D pinches are emitted in 0.5-1-μsec bursts and come generally at the third bounce. Occasionally (6 times out of 500) they observed 5–10 times greater neutron yield.

In the formal sessions S. A. Colgate of Livermore described the results of U. S. pinch-effect experiments done prior to the Kurchatov disclosure. The results are quite similar to the Russian results in that the neutron production ($\sim 10^8$ neutrons per discharge) agreed with that expected for a true thermonuclear reaction. The Livermore group has been able to prove experimentally what the Russians had surmised earlier—i.e. that the observed neutrons are not of thermonuclear origin. Measuring the neutron energies in nuclear emulsion showed that the center of mass of the reacting particles had been accelerated along the tube, so that the mechanism producing its neutrons was similar to an accelerator beam striking a target rather than to a hot plasma reaction like that in the interior of the sun.

The Livermore group suggests that the observed neutrons are due to deuterons which are accelerated by axial electric fields created by the growth of so-called $m = 0$ or sausage-type instabilities in the pinch. The accompanying rapid change in inductance could produce fields of sufficient magnitude

(Continued on p. 117)

THERMONUCLEAR BULL SESSION. Venice Conference provided many opportunities for informal exchange among thermonuclear researchers. Shown here starting at extreme left and proceeding clockwise are Akiezer (USSR), British interpreter, R. F. Post (Livermore), J. L. Tuck (Los Alamos), Dernirchanov (USSR), U. Facchini, conference secretary, S. A. Colgate (Livermore), W. Allis (MIT), unidentified individual, Melvin Gottlieb (Matterhorn), and R. Lüst (Gottingen). (Photo supplied by Colgate)

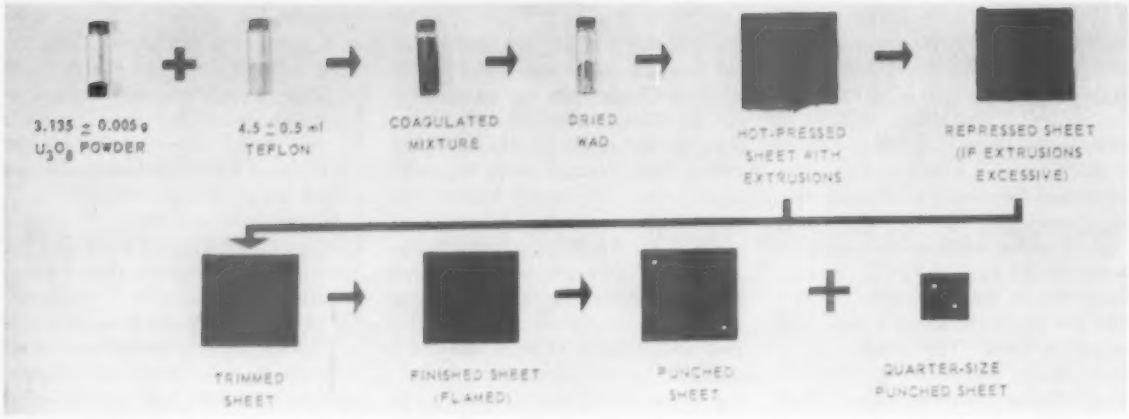

FIG. 1. Steps in fabricating Teflon fuel elements

Teflon Critical-Experiment Fuel Elements

By J. L. SWANSON and F. H. WELCH
Aircraft Nuclear Propulsion Dept., General Electric Co., Cincinnati, Ohio

Teflon, polytetrafluoroethylene, has been used for the body of a critical-experiment fuel element containing a homogeneous dispersion of enriched uranium oxide. The selection of this material was based upon the following criteria:

1. A flexible, sheet-type element provides a high degree of versatility for critical experiment usage because it can be used in layers equivalent to sheets of metallic or ceramic materials in a variety of direct-cycle fuel-element configurations.

2. The Teflon molecule is composed of carbon and fluorine atoms, both of which have relatively low neutron cross sections.

3. The quantity of uranium oxide (U_3O_8) is controlled so that each element is equivalent to 0.001-in.-thick uranium foil.

4. The use of uranium in the most stable oxide form, U_3O_8, eliminated the problem of air oxidation, as is encountered with metallic uranium or uranium alloys.

5. The low decomposition temperature of the Teflon (735° F) insures that in the event of a temperature excursion a critical experiment will fail at a much lower temperature than a critical experiment composed of metallic elements.

6. The uranium oxide is easily recovered from the Teflon by heating the fuel element in air.

Fabrication Process

A process was developed whereby an aqueous suspension of Teflon could be mixed with uranium oxide, coagulated, dried, and hot-pressed to form a tough, pliable sheet. A graphic flow sheet of the final process is shown in Fig. 1;

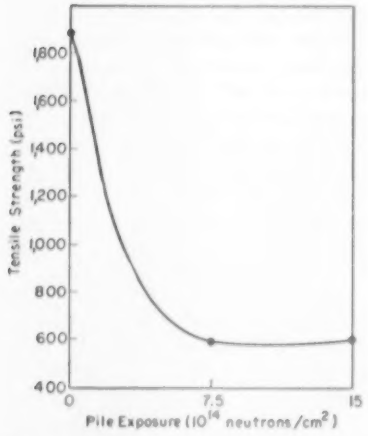

FIG. 2. Tensile strength of standard 4.5-mil Teflon fuel element as a function of reactor irradiation shows drastic decrease but shelf life (Fig. 3) is actual limiting factor

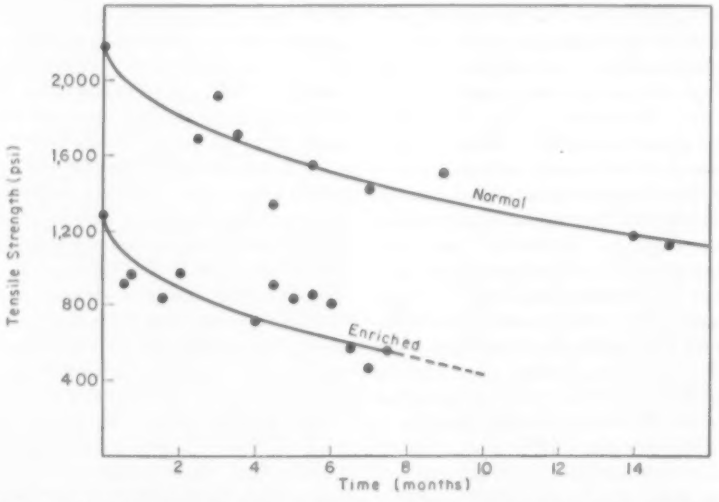

FIG. 3. Shelf-life study of tensile strength of enriched- and natural-U Teflon fuel elements. Greater activity of U^{235} leads to greater radiation-induced damage

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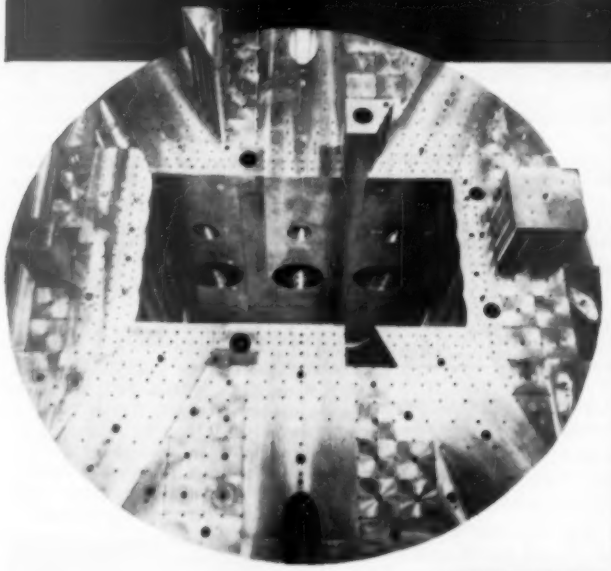

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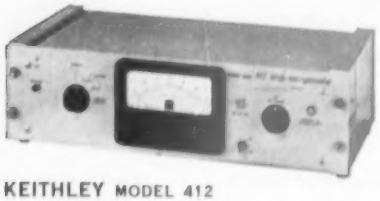

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Production Process

Step	*Specification*
Weighing	3.079–3.141 gm U_3O_8 (0.010 gm added to allow for punching of holes). Weighing limits 3.135 ± 0.005 gm
Mixing	5.18 ± 0.02 gm Teflon suspension (automatic Filamatic pipette)
Liquid removal	Partially oven-dried, moist wad of Teflon U_3O_8 remaining
Preheat	725° F, zero pressure, 30 sec
Hot press	725° F, ~25,000 lb, 1½ min
Cold press	Water-cooled, ~25,000 lb, 20 sec
Weigh	Mettler balance x.xxxx
Number	Impression of identification number—upper right hand corner
Trim	Remove large extrusions with scissors
Flame	Remove all extrusions or flashings by flaming over burner
Reweigh	Any fuel element losing 0.100 gm or more rejected as low in weight of oxide

the table gives process steps in detail. The hot-pressing dies were specially designed, and standard Loomis pressing platens were changed to thick, air-hardening tool steel. By introducing the double-weighing technique of the hot-pressed fuel element, as shown in the table, approximately 99% of the finished fuel elements were shown by chemical analysis to contain 3.1 gm of U_3O_8 ± 1%.

Approximately 60,000 natural-U fuel elements were fabricated in the course of process development. When fabrication of enriched fuel elements began maximum production rate was 320 fuel elements per 8-hr shift. Production was carried out under the limitation of 1 kg of U_3O_8 per shift in the production area.

After a total of 26,820 enriched fuel elements had been fabricated, production activities were discontinued. The production figures are as follows:

Good-available	21,498*
Good-analytical samples	784
Good-test samples	34
Scrap	4,504
Per cent scrap	16.4

The percentage of scrap from the total production was 16.8%, which was

* Five hundred twenty-seven fuel elements were rejected during assembly of the critical experiment as a precaution to reduce the possibility of falloff of small fragments from unevenly rounded corners. This criterion was established after the fuel elements were fabricated.

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about 3% less than anticipated. Following completion of the production run, the scrap elements were processed for recovery of U_3O_8 mixture by heating the Teflon-U_3O_8 in a platinum dish to vaporize off the Teflon.

Fuel-Element Properties

Fuel-element tensile strengths were tested with and without reactor irradiation.

Radiation studies. In-pile tests of the fuel element promised at least five years' service under predicted critical-experiment radiation conditions, as shown in Fig. 2. In practice, self-damage from U radiations limits one more as revealed in the following study.

Shelf-life tests. The tensile strengths of the Teflon U_3O_8 fuel elements were measured at various intervals of time after fabrication. It was found that the tensile strength decreased with increasing age as the chemical bonds in the Teflon were attacked by the radiation emitted by uranium. The breaking of the carbon-to-carbon bond in the Teflon polymer tends to reduce the size of the polymer molecule and alter the properties of the fuel element.

The same decrease in strength has been found for fuel elements containing either normal U_3O_8 or enriched U_3O_8, although the effect is more pronounced in the fuel elements containing enriched U_3O_8 because of the greater activity of U^{235}. Figure 3 shows the change in tensile strength of the two types of fuel elements as a function of age.

In both cases the tensile strength tends to level out after several months. Examination of enriched fuel elements nearly eighteen months old shows that they can still be handled and used without damage if moderate care is taken. However, bending to a sharp angle or folding will crack the fuel element.

Variations

Several experimental modifications were made to the standard Teflon-U_3O_8 fuel element in an attempt to increase the resistance to radiation from the contained uranium and consequently to increase the useful life of the elements. These included the use of an 0.003-in. Teflon-film cladding hot-branded to the Teflon-U_3O_8 fuel element, doubling the amount of Teflon in the formulation and varying the U_3O_8 particle size. None of these alternative formulations were particularly better than the one described here.

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Glass Fibers—A New Form for Reactor Fuels

By P. HARTECK and S. DONDES
Chemistry Department, Rensselaer Polytechnic Institute, Troy, New York

Uranium, plutonium and thorium can be incorporated as oxides in glass fibers to make nuclear-reactor fuels having unique properties. In a reactor so fueled and used as a radiation-chemistry source, recoil energy is readily available from fission products. As a heat source, the fibers offer a large heat-transfer surface.

The development of these fibers was inspired by the desire to use fission-product recoil energy more efficiently in radiation-chemistry processes. We have previously described (*1*) a method for fixing nitrogen by bringing air into contact with a fine dispersion of fissionable material. However, in the case of finely divided uranium oxide, only 10% of the fission products escape to transfer their energy to the chemical reactants. By incorporating the fissionable material in 1-micron glass fibers, fission-product utilization can be increased to >60% in the gas phase.

Fiber Fabrication

The fibrous glass may be prepared by any of the conventional methods. For example, the continuous-filament process may be used, particularly for coarser fibers. These can be woven into various shapes. One- to five-micron fibers may be made in the form of wool, and the density changed by compression from 0.005 gm/cm³ to about 1.0 gm/cm³. Fibers can be manufactured with softening points from below 600° C to above 1,000° C.

Fibers containing fissionable material. Fibers can contain uranium-233, uranium-235 or plutonium-239. U^{235} fibers have been made; U^{233} should necessitate no change in the process.

In the case of Pu^{239}, the radiological hazard and toxicity may conceivably be minimized by the introduction into glass fibers. Fabrication involves incorporating plutonium oxide as one of the melt constituents. The preliminary glass patty is formed in a closed system designed for handling plutonium. The patty is remelted and processed into fibers.

The stability of the fibers may be greater than that of metallic fuel elements. This is primarily due to the self-annealing characteristics of glass. Even 1-micron fibers are not damaged by gas cooling, i.e., with CO_2 or helium. Fibers with softening points approaching 1,000° C are in the realm of possibility. This would exceed the melting point of plutonium (640° C). The fibers are normally stable to oxidizing

FIG. 1. Twenty-five-micron glass-fiber strands containing 10% U_3O_8

What Fibers Have to Offer as Reactor Fuel

- Large heat-transfer area
- Chemical and thermal stability
- Operation up to 1,000° C
- Wide variation in content of fissionable and fertile material
- Versatility of structural form
- Fission products continuously removed by cooling medium
- Simple, inexpensive and conventional fabrication
- Simple reprocessing
- Inexpensive raw materials

and reducing gases and have only a slight solubility in boiling water.

Reprocessing the fibers involves simple treatment with hydrogen fluoride or fluorine and separating the gaseous silicon tetrafluoride and UF_6 by fractional condensation. Other fluorides, including fission products, are nonvolatile.

Fibers containing fertile material. Fertile materials, i.e., U^{238} and Th^{232}, can be put in glass fibers in the same way as the fissionable materials for use in breeder reactors.

In the case of Th^{232}, it is in a form in which the constituents other than thorium have low thermal-capture cross sections. Thus, for fibers containing 40% thorium by weight, 90% of the absorbed neutrons cause transformation into fissionable U^{233}. Since a large percentage of the fission products leave the fibers, the U^{233}-containing fibers may be used directly as fuel without expensive reprocessing.

Radiation Stability

To determine the effects of radiation, fibers containing uranium oxide (U_3O_8) were irradiated in the Brookhaven National Laboratory reactor. These fibers had a softening point of 650° C.

Natural uranium. One-micron fibers containing 2% natural U_3O_8 were irradiated for 24 hr at room temperature. The wool was sealed in a fused-silica container in an atmosphere of nitrous oxide. The neutron flux was 3×10^{12} n/cm²/sec. There was no evidence of radiation damage.

Samples containing 10% natural uranium oxide were irradiated in vacuum at 175° C for 10 days. The flux was 3.8×10^{12} n/cm²/sec. Again there was no evidence of damage.

Enriched uranium. Samples containing 10% uranium oxide enriched to at least 90% U^{235} were irradiated under the same conditions as for the previous samples.

Under the vacuum conditions, the glass wool tended to sinter together at about 300° C. This was caused by fiber overheating due to poor heat dissipation in vacuum. The sintering was reduced in a helium atmosphere, even at a relatively low pressure. In air at about 10 atmospheres, there was practically no sintering.

The fiber composition tested did not become brittle at room temperature. Although a fiber with a softening point of 1,000° C may become brittle at room temperature, it should work well in the range 150–400° C.

Effect of fiber diameter. To determine the effect of fiber diameter on radiation stability, 25-micron fibers containing 10% uranium oxide enriched to >90% U^{235} were exposed to 3.8×10^{12} n/cm²/sec in vacuum for 30 days at 175° C. Another sample was exposed to 3.0×10^{12} n/cm²/sec in vacuum for 10 days at 400° C. In neither case was sintering or damage observed. However, there was an apparent loss of strength.

Tensile strength. To determine radiation effects on the fiber tensile strength, 25-micron fibers containing 10% uranium enriched to >90% U^{235} were exposed to 2.5×10^{12} n/cm²/sec at about 45° C. The fibers were wound on aluminum support rods in aluminum containers filled with air at atmospheric pressure.

After irradiation for 681 hr, the aluminum rods were bent out of shape, but no visual effect on the fibers was noted. The following measurements were made:

Irradiation time (hr)	Tensile strength (lb/in.²)
0 (blank)	243,000
76	72,000
226	65,000
681	61,000

Extrapolation of these results indicates adequate tensile strength without deformation for complete consumption of U^{235}. This compares with the tensile strength of the following unirradiated materials (*2*): copper wire ½(hard drawn), 60,000–70,000; iron wire (annealed), 50,000–60,000; and platinum wire, 50,000.

Surface effects. To determine irradiation effects on the fiber surface, electron shadowgraphs were taken of the blank sample and the sample irradiated for 681 hr. These are shown in the illustration.

The fibers appear to be severely corroded. Fresh fibers should have a perfectly smooth surface at this magnification. The more severe corrosion of the irradiated fibers may be due to the higher temperature used during irradiation. It is anticipated that the development of a more durable glass fiber will alleviate this problem.

Fission-Product Utilization

Measurements were made to determine the efficiency of utilization of recoil fission fragments from glass wool.

Ten-milligram samples of 1-micron wool were prepared containing 10% uranium oxide enriched to >90% U^{235}.

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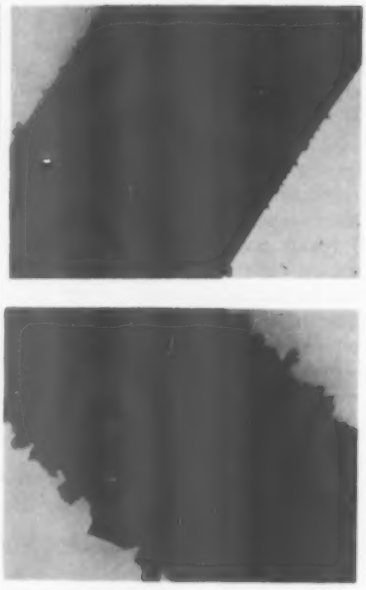

FIG. 2. Electron shadowgraphs of 25-micron fibers containing 10% uranium oxide: top, unirradiated; bottom, 681-hr irradiation with flux of 2.5×10^{12} n/cm²/sec

The samples were sealed in fused-silica vessels in an atmosphere of ammonia or methane at about 10 atmospheres. The irradiation flux was 2.5×10^{12} n/cm²/sec at 10° C for 1–2 hr.

The gaseous products were measured by low-temperature vapor-pressure techniques. It was determined that 60–75% of the kinetic energy of the fission fragments had been absorbed in the gas phase.

The methane products were predominantly hydrogen and ethane, with small amounts of higher hydrocarbons ($G_{C_nH_m} = \sim 10$). The ammonia products were nitrogen and hydrogen, with very small amounts of hydrazine ($G_{N_2H_4} = \sim 5$).

A similar irradiation in liquid ammonia (products were nitrogen, hydrogen and small amounts of hydrazine) indicated 80–90% of the fission-fragment energy had been transferred to the liquid phase. This improvement in energy transfer can be ascribed to the higher liquid density, shorter fission-fragment range and consequently fewer fragments absorbed by adjacent fibers.

To determine the fraction of the fission fragments ejected from the fibers into the gases and liquid, the fibers were measured, after liquid evaporation and removal from the vessel, for gamma radiation with a counting-rate meter. The fibers were then washed with a warm dilute solution of nitric acid and

dried. In the case of the gas irradiation, the untreated fibers read 13,000 cpm with a background of 55 cpm; after treatment, the fibers read 2,200 cpm. From the liquid irradiation, untreated fibers read 9,900 cpm with a 50-cpm background and 340 cpm after treatment.

Applications

Glass fibers containing fissionable and fertile material offer possibilities for application in two general fields: (1) use of fission-product recoil energy for radiation-chemical processes; (2) as fuel in testing and power reactors.

Radiation chemistry. Fuel elements for use in radiation chemistry would consist of 1–10-micron-diameter fibers containing 1–50% by weight of U^{233}, U^{235} or Pu^{239}.

To date, the most promising example of producing chemicals with reactor radiation is nitrogen fixation (*1*). One mole of U^{235} burned up will produce over 250 tons of NO_2. Although our work was accomplished primarily in closed static systems, at our suggestion a recent dynamic-flow experiment has been performed (*3*) in a loop in the reflector of the Brookhaven reactor. Flux was 1×10^{12} n/cm²/sec. Boron was substituted for uranium as a Pyrex-glass fiber to give the reaction $B^{10}(n,\alpha)Li^7$ with an alpha energy of about 2.5 Mev. The Li^7 may remain in the fiber and therefore be omitted from efficiency consideration. Coolant air at 6 atmospheres and 100° C was used. Nitrogen dioxide was produced (10% HNO_3), but the efficiency of the process has not yet been evaluated.

Reactor radiation for synthesizing chemicals from hydrocarbons is being extensively investigated. We are studying this using fibers containing U^{235}.

Pure carbon dioxide is less than 0.1% decomposed by ionizing radiation. Adding about 2% NO_2 to the CO_2 produces carbon monoxide and oxygen with a G of 8–9. The products may be burned for heat or the carbon monoxide separated from oxygen and used in the Fischer-Tropsch reaction for synthetic fuels.

A somewhat related technique is the production of high-level gamma-ray sources for sterilization and other processes. Fission products, which are expelled from the fibers, can be continuously removed with the coolant and then separated from it.

Test and power reactors. For materials-testing and heat-source purposes, the glass fuel may be used in the

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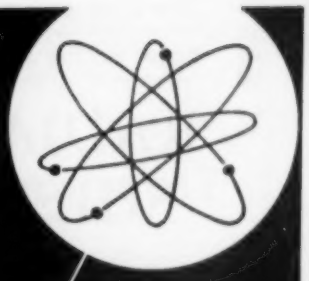

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form of fibers, rods, tubes, ribbons, etc., of 10–1,000 microns. The pressure drop through the glass wool may be made relatively small, and the fibers are extremely low in cost compared with other forms of solid fuel elements.

The low thermal-neutron-capture cross sections of the glass-fiber materials lend themselves to use in a high-flux materials-testing reactor. For example, with about 450 liters of heavy water as moderator and coolant, a coolant temperature rise of 30° C and flow of about 450 liters/sec, a flux of about 5×10^{14} n/cm²/sec is obtainable. The power of this reactor would be about 57 Mw. This possibility is enhanced by the lower costs of fuel processing and fabrication.

Gas-cooled power reactors operating at about 1,000° C could use glass fuel. Aluminum silicate and silica-glass fibers are now used in insulation devices operating at 1,100° C—incorporation of fissionable material should not radically reduce the softening point. Since a large proportion of the fission fragments are transferred to the coolant stream, they are readily separated by filtration, adsorption or electrostatic precipitation. High-temperature steam may be produced directly but depends primarily on the solubility of the fibers under these conditions; slightly acidic water may overcome this problem.

There is a further advantage for breeder power reactors. Fission-product recoil from the fiber surface would leave the fibers virtually free of fission products. Thus, processing to separate out the fissionable material would be simplified.

* * *

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The authors would like to acknowledge the kind cooperation of the Owens-Corning Fiberglas Corp. for developing and supplying the experimental samples of fibrous glass containing uranium that were used in the investigation. The physical-property measurements and electron shadowgraphs of the fibers before and after irradiation were made in the Research Laboratories of the Owens-Corning Fiberglas Corp. We are indebted to L. P. Biefeld and J. W. Michener of the Owens-Corning Fiberglas Corporation for their close cooperation and helpful suggestions.

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Whither Reactor Development?

Some problems pinpointed by Alvin M. Weinberg

Reactor development has been greatly influenced by its own nature, Alvin M. Weinberg believes. The director of Oak Ridge National Laboratory explained to a recent conference of Latin American nuclear scientists that therein lies much of the reason why certain groups and certain nations are committed to particular reactor types.

The massiveness of reactor technology, he says—in the sense that hydraulics or bridge-building are massive—has had these effects: (1) it consists of relatively few very large devices, hence has fairly limited possibilities for experiment; (2) each project resembles an inverted pyramid, in that a single idea requires an ever-increasing amount of effort for its implementation, and hence few of the 100-odd possible reactor types can be worked on seriously; (3) the reactor experiment—a relatively small-scale reactor embodying some, but not all, the essential features of a full-scale reactor—has become an accepted developmental device for reactor technology, removing some of the expense and inertia involved; and (4) the technology has so much inertia that once a line of development is chosen it becomes difficult to move to another line.

Thus the history of a line of development weighs almost as heavily as its intrinsic merit in deciding the future. For example the preponderance of pressurized-water types in the U. S. civilian program is largely attributable to the original great success of *Nautilus*, Weinberg says. The lack of concern with gas-cooled systems in the U. S., on the other hand, is connected partly with the relatively high capital costs of these systems which make them less attractive economically wherever high fixed charges prevail, and partly with the original inconclusive attempt to develop the Daniels pile, a high-temperature, gas-cooled ceramic reactor.

Gas or Liquid Coolant?

Among the issues on which there is sharp disagreement among competing groups is the matter of coolant choice: gas or liquid? Gas systems because of their size seem to have higher capital costs, but this tends to be balanced by lower operating costs, thanks to better neutron economy. Conversely liquid systems have lower capital costs, being smaller, and higher operating costs, having poorer neutron economy. Thus, Weinberg points out, the choice between the two is much affected by the bookkeeping. In Italy where private utility fixed charges are extremely high, a pressurized-water reactor has been bought; in England, where the bookkeeping makes fixed charges lower, gas-cooled systems are in strong vogue.

Solid or Liquid Fuel?

Another, more fundamental area of disagreement among reactor designers is fuel choice: solid or liquid? Weinberg paraphrases this to ask "whether a reactor is basically a chemical plant (homogeneous) or a mechanical plant (heterogeneous). Is the essential rationalization of reactors to be a mechanical rationalization, or a chemical rationalization?"

The essential difference between the two types is strikingly borne out by comparing the Experimental Boiling Water Reactor and the Homogeneous Reactor Test. EBWR is representative of heterogeneous, HRT of homogeneous reactors; one looks very simple, the other very complex. As far as external equipment is concerned, heterogeneous fixed-fuel systems are simpler than homogeneous circulating-fuel types. On the other hand, the core of a homogeneous system is very much simpler than the core of a heterogeneous system: there are no control rods and no fuel elements. This explains partly why the externals of a circulating system are more complicated—control depends on varying fuel concentration, which requires a complicated system for strict control of fissionable material.

Two other factors add to the external complexity of the homogeneous system: It combines some continuous chemical treatment of fuel with reactor operation, and, because of the need for absolute leak-tightness, it requires a leak-detection system. The former serves as reminder that the aims of HRT are much more ambitious than those of EBWR in that in HRT chemical treatment of the fuel is an integral part of the system, whereas in a heterogeneous reactor "chemical and metallurgical treatment is left as an exercise for the chemist and the metallurgist. In the heterogeneous system, it is the fuel elements which are expendable and replaceable; in the homogeneous system, it is the heat exchange equipment (and core) which is expendable and replaceable. It is the belief that reliability and economy of the heat exchange equipment can be made to exceed reliability and economy of the fuel element that in a sense motivates the whole homogeneous development. It is the contrary belief that motivates the heterogeneous development."

Comparing the various elements of EBWR and HRT, Weinberg shows that all those that are complex in one are simple in the other and vice versa. "It is no wonder," he concludes, "that there is sharp disagreement as to the relative merits of the basic principle. The resolution of this basic issue must await construction and operation of both reactor types."

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Ion Beams Provide Surface Inspection

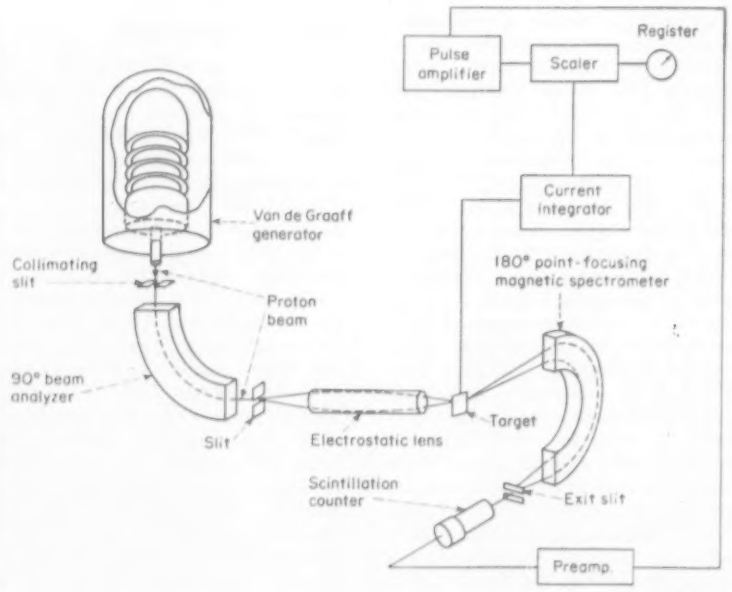
Beams of protons or deuterons from a Van de Graaff accelerator are sensitive probes for analysis of the nature of surfaces. Since their penetration is limited to a few microns, they can be used to analyze surface films in the presence of a high "background" in the body of the material. The method is based on detection of protons elastically scattered from a proton beam or produced in d,p reactions by a beam of deuterons. The method has been developed and reported by physicists at the Stanford Research Institute.*

In the proton analysis the accelerator beam is analyzed by a bending magnet and directed through a slit onto the surface (see figure). Protons that are elastically scattered at 150 deg are collimated by a second slit, analyzed with a high-resolution magnetic spectrometer, and counted with a scintillation crystal. The number entering the spectrometer with a given energy tells the number of atoms of a particular weight that are in the surface. Elements of mass numbers less than ~40 can be separately identified. The quantity and approximate mass of a heavier element can be determined, but its precise identity must come from other sources.

When deuterons are used, analysis of the energy of protons produced in nuclear reactions is made with a scintillation crystal. A thin foil serves to exclude light and stop recoiling deuterons. As an example, one can look for carbon and oxygen by means of the $C^{12}(d,p)C^{13}$ and $O^{16}(d,p)O^{17}$ reactions. When 1.4-Mev deuterons impinge on the surface, two proton groups come from the oxygen reaction and a single one from the carbon reaction. Calibration is accomplished by exposing samples of known carbon and oxygen concentrations in the apparatus. With available refinements, the system is estimated to be capable of detecting surface concentrations of 2.0×10^{-8} gm/cm² of oxygen and 6×10^{-9} gm/cm² of carbon.

The method is limited to materials that will withstand the bombardment: metals, glasses, ceramics, and some high-melting polymers such as Teflon. It has been applied to the analysis of films deposited on metals in an explosion and is considered appropriate also for research in solid-state-diffusion studies and lubrication-film research.

* S. Rubin, T. O. Passell, L. E. Bailey, *Analytical Chemistry* **29**, 736 (1937) and S. Rubin, T. O. Passell, L. E. Bailey, Surface analysis with a 2-million volt Van de Graaff (National Symposium on Instrumentation Analysis of the Instrument Society of America, Chicago, Ill., June 13–15, 1957).



Unesco Conference on Radioisotope Use

Russian papers are most numerous among the first 150 selected for the coming Paris conference on uses of radioisotopes in research. The conference will be held in Paris, September 9–20, under the sponsorship of Unesco, the United Nations Educational, Scientific, and Cultural Organization. A total of 220 papers will be presented.

Charles Coryell is the American member of the Unesco committee that is planning the conference. The official United States delegation will consist of Commissioner Willard F. Libby, Raymond Edwards, and George Manov, all of the AEC. Presiding at the conference will be Sir John Cockcroft, Nobel laureate and director of England's AERE at Harwell.

Twenty nations are represented among the first 150 papers, abstracts of which were recently released by Unesco. The USSR is the big contributor with 41. The United Kingdom has contributed 26, France 23, Belgium and the United States 13 each, Japan 10, the Netherlands 5, and Sweden 3. Two papers have come from each of the following countries: Canada, Czechoslovakia, Denmark, Israel, Poland, and Spain. These countries have contributed one each: Australia, Egypt, Finland, Germany, Ghana, New Caledonia.

Plans for the conference were drawn up by a committee representing nine nations and four international scientific organizations meeting at Unesco House in Paris last January. The papers at the conference will be limited in subject matter to original research of "strictly scientific character." They will include new ideas or methods in the use of radioisotopes, production of radioisotopes, and measuring techniques. Machine-made radiation is excluded.

The original prospectus divides subject categories into plenary sessions on new developments in measuring techniques and radioisotope production and two sections devoted respectively to physical sciences and biological sciences.

A rough classification of the first 150 abstracts shows that 20 papers are devoted to radioisotope production and measuring techniques. Thirty are devoted to such physics subjects as polymerization, solid-state investigations, ion exchange, and metallurgy. Biologists are the heavy contributors with 56 papers devoted to animal biology and 20 to botany. Eighteen papers are devoted to subjects of chemistry, 4 to geophysics, and 2 to engineering.

Representative papers. Among interesting papers at the conference is one describing a new technique for preparing planar sources of alpha, beta, and gamma radiation by Petrova and others of the USSR. They incorporate the radioactive isotope in an inorganic enamel or the oxide film on aluminum to obtain high yield but freedom from contamination. In another new technique C. N. Turton of England mixes C^{14} with Kr^{85}. The beta radiation from the krypton induces the labeling of organics with the radioactive carbon by breaking bonds to permit entry by C^{14}.

In the field of dosimetry another Russian group will report investigations of effective electron spectra in beta and gamma fields directed toward more accurate calibration of chambers, counting tubes, and films. Taplin of the University of California at Los Angeles will report on new dosimetry techniques with trichlorethylene–phenol-red systems. Behounek of Prague will describe measurements of inaccessible activities based on the ionization produced in a current of air.

Fission-fragment-recoil separation is the subject of experiments reported by Henry and Herczeg of the French Commissariat à l'Energie Atomique.

Antiquarians Find Radiation Useful

Cartoons of archeologists in the desert may have to be modernized to include more than pencil, paper, and pith helmet. They are now using radiation as a tool of study in addition to radiocarbon dating.

A recent Brookhaven National Laboratory report describes investigations pointed toward identifying the clays of ancient potteries. The information is useful in tracing ancient trade patterns. Neutron irradiation produces activity dominated by Na^{24} and Mn^{56}. The ratio of the two turns out to be a good identification tag for the clay.

Among the esoteric papers to be presented at the Paris Unesco conference (above) is one by three Japanese who have investigated the materials of art objects more than 1,200 years old with backscattered beta rays. They have studied the thickness of gold plating on the largest Buddha image in the world kept in the Todaiji Temple at Nara and the chemical compositions of glasses, bronzes, and glazes of objects in the 1,200-yr-old Shosoin Treasury.

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VAN DE GRAAFF installation at Gulf's newly opened Harmarville, Pa., nuclear laboratory is one of nine machines that large oil companies are now using in petrochemical research. This NUCLEONICS survey shows the . . .

Oil Industry Enlarging Its Radiation Research

Radiation research in the petroleum industry is in a conspicuous growth period. Within the past four months four major oil companies—Cities Service, Gulf, Sinclair, and the Texas Co.—have opened or announced plans to build radiation facilities. Indications are that Standard Oil of Indiana will follow suit in the immediate future.

To get a comprehensive picture of nuclear activities NUCLEONICS has conducted a special survey of the companies in the field. Seventeen of the major companies responded with descriptions of their plans, research programs, and facilities.

The petroleum industry is probably the most active in exploring applications of radiation and other nuclear techniques. Initially the companies turned to independent research groups for their nuclear research. As the volume increased, the industry started to invest in its own accelerators, radioactive sources, hot cells and tracer laboratories. The present survey shows 11 particle accelerators in use or planned for installation—nine Van de Graaff's, a linear accelerator, and a resonant transformer. Six Co^{60} sources are listed, ranging from 15 to 35,000 curies. Two companies are conducting reactor irradiations; one group is planning to build a reactor; and three laboratories have or will have spent fuel elements. As is usual in this highly competitive industry, it was easy to learn about facilities, comparatively difficult to learn just what research projects are currently under way or being considered.

The complete survey, indicating facilities, equipment and major programs, follows:

Atlantic Refining Co. has been working since 1955 with a 1-Mev resonant-transformer electron accelerator at its Philadelphia laboratories. It also has a loop to test petroleum samples at Brookhaven National Laboratory's reactor. To date, Atlantic has produced sample quantities of octane by bombarding butane hydrocarbons with electron beams.

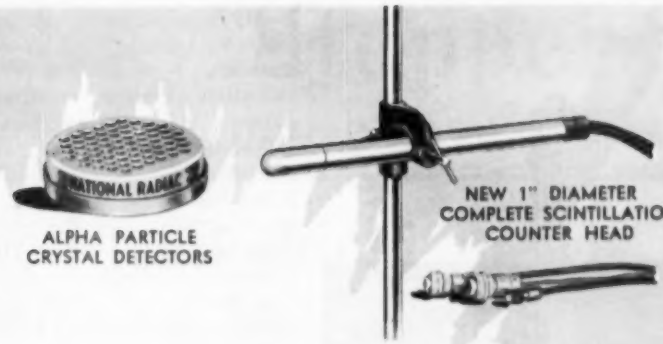
American Oil Co. uses radioactive-tracer techniques at its Texas City laboratory. They are studying such problems as the origin of engine deposits by labeling different fuel components with C^{14}.

Cities Service Co. opened a radiation facility at its new Cranbury, N. J., research center during June. Presently the radiation laboratory has 6,000 curies of Co^{60} which was obtained from Brookhaven. Radiation work is mainly on effects in improving various types of refinery processes, fuel and lubricant products.

Continental Oil Co., at its nuclear research laboratory being constructed at Ponca City, Okla., will work with radiotracers and gamma radiation. The laboratory will have a Co^{60} source capable of 10^6 r/hr and will have radiotracer facilities for "developing various techniques and instruments useful to oil production and refining."

Esso Research & Engineering Corp., research arm of Standard Oil of New Jersey, employs three facilities—Esso Research Center, Brookhaven and Battelle Memorial Institute. At the Linden, N. J., research center, a 3,500-c Co^{60} source is housed in a hot laboratory, which was completed in 1955 (NU, Jan. '56, p. R10); a laboratory for working with low-strength radioactive isotopes is located in an adjacent building. Specific studies determine what gamma rays will do, chemically, to oil materials, measure effects of lubricants on auto engine wear, etc. At Battelle's swimming-pool reactor experiments are aimed at perfecting ways of using nuclear radiation in petroleum refining and in petrochemical production while at Brookhaven there is work of an exploratory nature in the reactor. From past tests on a small-scale basis, for example, sample quantities of gasoline and other oil products have been produced with the aid of gamma radiation. The company spends more than $1-million annually on nuclear experiments, of which Battelle receives $250,000 each year during the course of a three year contract.

Gulf Oil Corp., at its newly completed $3-million A. W. Mellon Nuclear Science Laboratory in Harmarville, Pa., employs a 3-Mev Van de Graaff accelerator to probe the applicability of radiation to refining. Their Van de Graaff is equipped to accelerate both positive ions and electrons. The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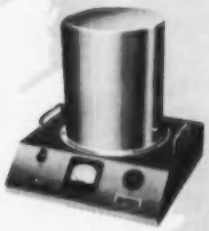
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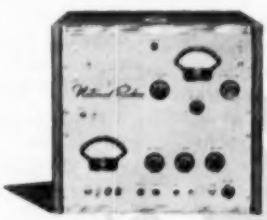
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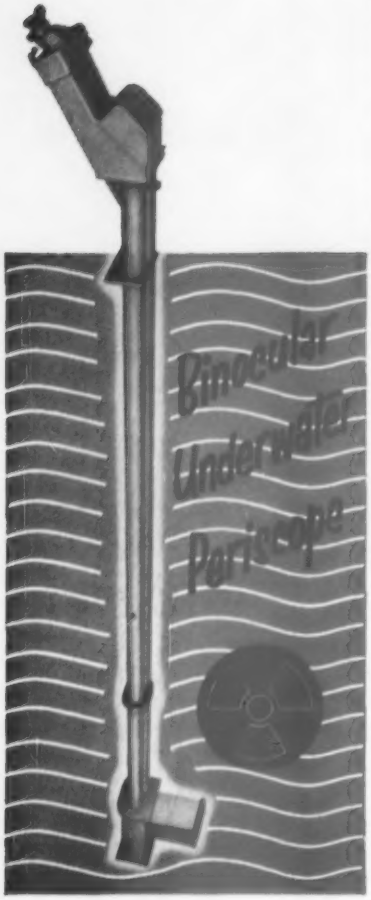

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facility includes a radiochemistry laboratory for handling highly radioactive materials. Work falls into two fields: radiation chemistry and nuclear physics.

Humble Oil & Refining Co., a Standard Oil of N. J. subsidiary, utilizes a 2-Mev Van de Graaff positive-ion accelerator as the primary research tool at its Baytown, Texas, refinery. Humble is basically concerned with what radiation does to hydrocarbon molecules making up petroleum.

Magnolia Petroleum Co., a Socony Mobil Co. subsidiary, investigates exploration and production problems at its field-research laboratory in Dallas. To improve interpretation of existing radioactive logging techniques, Magnolia has two Van de Graaff positive-ion accelerators—0.5 and 2.0 Mev—and a 15-c Co^{60} gamma-ray irradiator used for active thermoluminescence studies of carbonate rocks.

Shell Development Co., wholly-owned subsidiary of Shell Oil Co., has two radiation centers—at Houston, Texas and Emeryville, Calif. The Houston facility concentrates on exploration and production research of natural petroleum; it has a 2-Mev Van de Graaff positive-ion accelerator and facilities to handle radioactive isotopes. The Emeryville unit, opened last fall, has a 3-Mev Van de Graaff electron accelerator to study radiation effects on petroleum and its products, besides applying radiation in fabricating petroleum and byproducts.

Sinclair Research Laboratories, Inc., a Sinclair Oil Co. subsidiary, opened its facilities in Harvey, Ill., last April (NU, July '57, p. 108). Spent fuel elements from AEC's Materials Testing Reactor at Arco, Idaho, are a gamma-ray source. The laboratory is composed of a radioactive tracer section and a radiation section where scientists conduct "research on the effects of gamma radiation on petroleum processes and products" and the application of tracers to the oil industry.

Socony Mobil Oil Co. is in the process of revamping its nuclear-research facilities. Its present facility at Paulsboro, N. J., will be enlarged and incorporated in a nuclear center which is in early construction stages at Princeton, N. J. Here Socony will have a 2-Mev Van de Graaff electron accelerator, two hot laboratories equipped to handle spent fuel elements, and Co^{60}. Additionally Socony will cooperate with a 10-company combine in operating a 5-Mw pool-type reactor at Plainsboro, near Princeton. These two centers will do basic research and explore hydrocarbon cracking to produce high octane gas, and fabrication of new byproducts.

Standard Oil Co. of Calif.'s subsidiary, California Research Corp., centers nuclear research in Richmond where there is a 2-Mev Van de Graaff electron accelerator and a radiation laboratory with a Co^{60} source delivering about 200,000 r/hr. Primary nuclear aim is to use gamma rays in testing effects of radiation on lubricants, hydraulic fluids, greases and other materials.

Standard Oil Co. of Indiana is designing its Whiting, Ind., research center to accommodate an accelerator of several million electron volts. Completion date and operational detail are not available, but Standard Oil reports that it presently contracts with independent research groups on radiation applications in petroleum processing.

Sun Oil Co., Philadelphia, has a limited amount of radiation research taking place, but it employs outside assistance. Sun reports that its present work load does not "justify a capital expenditure."

The Texas Co. joined the rank of oil companies active in radiation research when it announced in June that it would build a nuclear laboratory at its research center in Beacon, N. Y. The laboratory will be equipped with three different radiation sources—a 6-Mev linear accelerator; a 3-Mev Van de Graaff positive-ion generator; and a 35,000-c Co^{60} source, now under irradiation at Chalk River, Canada. When the facility is completed next spring, Texaco "intends to explore the possibility of using nuclear energy to practical advantage in its operation" with emphasis on increasing radioisotope investigations that bear on the daily problems in the use of lubricants and fuels. Researchers hope to enlarge their understanding of how greases and oils lubricate, how wear and corrosion occur, why certain jet fuels are better than others.

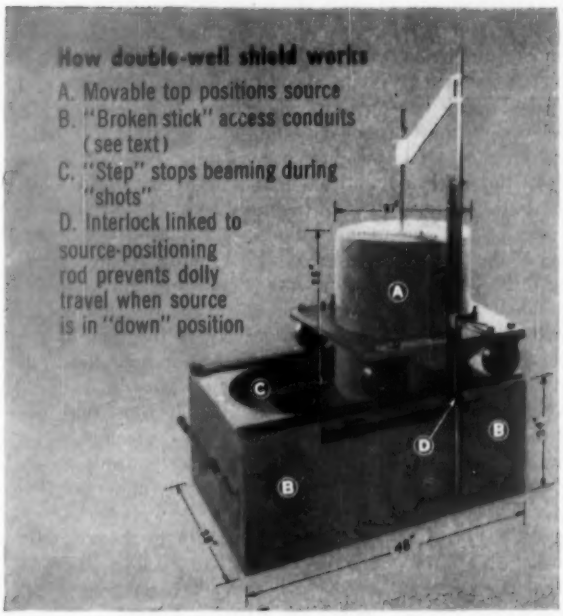
Tidewater Oil Co. reports it is doing very little outside of some experimental product testing, but they are watching developments in this field closely.

Union Oil Co. of Calif. has used outside gamma-ray facilities involving Co^{60}, reactors, and spent fuel elements. They study radiation effects on petroleum hydrocarbons and other products. Future plans call for continuing investigation of how Union can best apply radiation.

New Ray Stoppers

NATIONAL LEAD REPORTS RECENT DEVELOPMENTS IN LEAD SHIELDING

Double-test-well lead shield speeds sample irradiation by cobalt-60



To speed cobalt-60 irradiation experiments, National Carbon Company is now using a novel double-test-well shield built by National Lead*.

The device consists of two main parts.

The bottom shield, containing the wells, is stationary. During irradiation in one well the other is set up for the next experiment. The "step" prevents "beaming". "Broken stick" conduits provide access to the wells for themocouple leads or other test equipment.

The top shield, containing a new-type 2000-curie-source capsule, positions this source at the desired height in the appropriate test well. It also provides for a safety interlock. And doubles as the shipping container for the source.

Design meets four basic objectives

Both shields are carefully designed weldments . . . ca... mild steel; cavity linings, stainless steel . . . filled by a special National Lead process with high-density, void-free lead. This construction and the geometry provide for:

1. A large volume of high intensity irradiations without exceeding a 0.1 mr/hr external level;
2. Reproducible or variable irradiation rates;
3. Uniform dosage over the surface of large samples;
4. Irradiations over a broad range of temperatures.

*From a design developed by J. A. Ghormley and C. J. Hochanadel at Oak Ridge National Laboratory, operated by Union Carbide Nuclear Company for the AEC.

National Lead offers "low-count" lead to isotope users

From time to time National Lead receives lead of extremely low radioactivity.

Lead of this type has proved extremely useful as shielding where background "noise" is a critical factor.

Laboratories and instrument makers wishing to be advised of "dead" lead availability should subscribe to this fact by writing National Lead.

ADDRESS INQUIRIES concerning low-activity lead, lead shielding devices, lead brick or other lead shielding materials to your nearest National Lead office or warehouse or write:-

New lead-filled accelerator beam hole shield

Five-inch all-around lead protection is provided by this National Lead-produced "Combination Radioactive Material Shipping Container and Van de Graaff Accelerator Beam Hole Shield."

Despite its high protection and built-in extra utility, this 28-inch high, 14-inch diameter unit weighs only 1500 pounds and is unusually easy to handle. Note above-center-of-gravity location of lifting lugs, handled slide-in plugs, non-tip base. Cavity is stainless steel lined. Outer case is carbon steel.

←This unit (one of a pair made by National Lead) is used as a storage cask for Co-60 in addition to its other functions.

NATIONAL LEAD SHIELDING

NATIONAL LEAD COMPANY
General Offices: 111 Broadway, New York 6

Vol. 15, No. 8 - August, 1957

Kewaunee

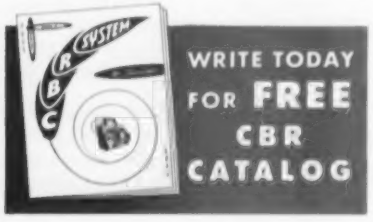
REMOTE CONTROLLED RADIOCHEMISTRY LABORATORY

PORTABLE 2-INCH LEAD SHIELDED "CAVE" FOR WET PRECIPITATION CHEMISTRY

To meet the heavy shielding demands of strong gamma emitters, the Kewaunee remote controlled CBR* laboratory is fitted with a portable lead enclosure. Designed to permit technicians to work remotely with constant temperature hot baths, cold baths, reagent racks, centrifuge, cone mounts, working racks, reagent storage—as easily as with the hands.

Portable shielding never becomes radiocontaminated—may be moved as required to another CBR unit.

If you're working with radiochemistry, investigate the Kewaunee remote controlled CBR laboratory – for greater personnel safety, lower operating expense, improved quality control, maximum space efficiency.



*CBR—Chemical • Biological • Radiological

Kewaunee

KEWAUNEE MANUFACTURING COMPANY
5083 S. Center St., Adrian, Michigan

REPRESENTATIVES IN PRINCIPAL CITIES

LETTERS

Quehanna Reactor

DEAR SIR:

I would like to correct a misconception that was published in the April '57 issue of NUCLEONICS (p. 22), which carried a listing of all of the U. S. reactor builders.

In the listing, you showed Daystrom as a builder of our reactor at Quehanna, Pennsylvania, and Curtiss-Wright as the customer. This is quite inaccurate, since the Curtiss-Wright reactor now under construction at our Research and Development Center at Quehanna, Pennsylvania, was designed and is being built under the direction of the Research Div. of Curtiss-Wright in all respects with regard to the nuclear physics of the reactor itself, fuel elements, controls and so forth. The other principal features of the facility building, including the general layout, waste disposal and other facilities, were all done by the Research Division.

The reactor is not being provided by Daystrom. Daystrom is providing structural iron bridges that support the reactor and certain instruments, the control-rod-drive mechanisms and the aluminum support structure for the swimming-pool reactor. These are in accordance with Curtiss-Wright designs and specifications. This represents about a $55,000 portion of the $2,500,000 facility.

We are very anxious to correct this misinformation, since the Research Division of Curtiss-Wright has a Nuclear Power Dept. that has been working for the past five years on all facets of reactor research and design under contract with the USAF and the AEC.

—KENNETH CAMPBELL
General Manager, Research Div.
Curtiss-Wright Corp.
Clifton, N. J.

What's in a Name?

DEAR SIR:

For some time many of us engaged in the different branches of radiation protection have felt that there is a need for a good term to express the general scope of our varied activities. I consider such activities to include health physics, radiological safety, criticality, certain aspects of industrial hygiene, radiation chemistry, engineering, sanitation, electronics, biophysics, etc. Although "health physics" is frequently used to embrace all of these activities, many of those concerned justly object to being called physicists.

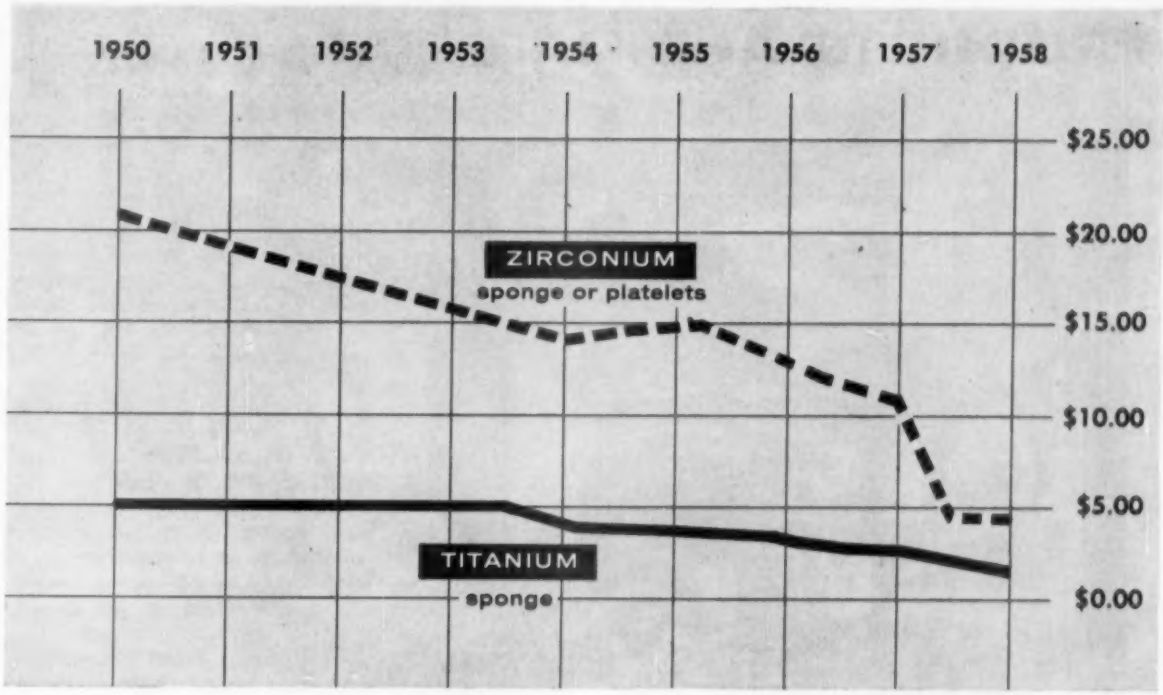
Lauriston S. Taylor, in a talk before the Health Physics Society in Columbus, Ohio, in 1955, suggested "radiation hygiene" to describe the general profession. Handbook 61 of the National Committee on Radiation Protection proposes the title "A Radiation Hygiene Act" for state radiation-protection legislation. It would appear that this term is the best suited to describe the types of work included.

There are certain objections to the use of the term "hygiene" because of its association with school nurses and dental technicians. However, the dictionary definition shows that it is probably the correct term, and its long use in the industrial-hygiene field has served to disassociate it with the above connotations. The natural qualifying term that would limit it to the field of atomic energy and radiation would be "radiological." This term was discussed extensively at the time of the forming of the Radiation Research Society several years ago. It was generally agreed at that time that the medical profession had preempted the term "radiology" and that radiologists were almost universally understood to be physicians.

It is unfortunate, in my opinion, that the Health Physics Society chose to select that particular name since it will undoubtedly tend to limit its activities somewhat in the future. I say this because I am aware of several instances of well qualified, potential candidates for American Industrial Hygiene Society membership who have chosen not to apply for membership because of the term "industrial." The alternative and more proper term of "occupational hygiene" would have precluded this. It is pertinent to this discussion to note that after a number of years of discussion on the subject, a national industrial medical group chose to change its name to one embracing the term "occupational medicine."

Such prolonged discussions of terms may appear to some to be quibbling, but it is my sincere opinion that the proper use of terms such as these has a profound effect on the general impression made within the scientific and industrial communities as well as among the general public.

—HANSON BLATZ
Health and Safety Laboratory
U. S. Atomic Energy Commission
New York, New York



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Zirconium from the new plant will sell for considerably less than current prices. Here's why: U.S.I. will use the most economical production technique ever developed for reducing metallic chlorides — a semi-continuous sodium reduction process. This process has possibilities of reducing titanium prices in the future as well.

So think again about zirconium and titanium for industrial equipment. Remember that they are lighter than other metals — a pound goes farther. Remember that they are more durable than other metals—a fabricated product lasts longer.

Write to Bill Greenleaf, U.S.I. Manager of Metals Department, for more information on these new metals from U.S.I.

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To answer your questions about zirconium and its relative, hafnium, U.S.I. has prepared an informative new booklet—"ZIRCONIUM and HAFNIUM." The booklet gives the important facts on these materials . . . lists mechanical and physical properties of both . . . describes briefly the new semi-continuous sodium reduction process for their production.

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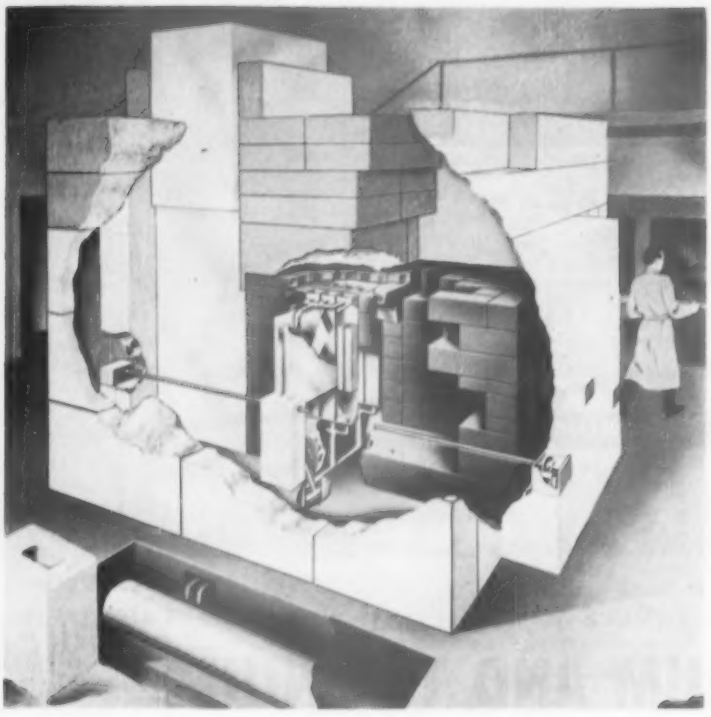
PRODUCTS AND MATERIALS



10-Kw Argonaut-Type Reactor Developed

Argonaut-type education, training and research reactor operating at 10 kw is called the "Educator." It is water- and graphite-moderated and has graphite reflection system. Low operating level minimizes excess reactivity and amount of contained fission products is small. Fuel is ~3.8 kg of U^{235} at 20% enrichment.

Core construction. Basic element of the reactor is a rectangular prism, $5 \times 5 \times 4$ ft constructed of graphite bars. Fuel plates, arranged in 24 bundles, are set into prism in six aluminum boxes through which cooling water circulates. Construction provides for three large, plane neutron sources and a thermal column. For shielding experiments and others, tested structures are placed against thermal column or in water shield tank. Flux density at core's center is 10^{11} $n/cm^2/sec$.

Cooling system. Water pumped from storage tank flows upwards, past fuel plates and out of top of fuel boxes through over-flow pipes. Quick-dump valve when tripped drops water from fuel boxes into storage tank. Additional safety feature is diaphragm that rims two rows of fuel boxes. It will rupture at pressures <25 psi thereby discharging moderator into shielded cooling-machinery pit.

Control system. Four swinging-arm-type cadmium control rods fit into pockets in the graphite core structure. Magnesium plate surrounds pocket to prevent blocking. By turning shaft, one can swing rods in or out of space between fuel boxes. In an emergency cadmium absorbers drop into reactor. Three of the four control elements, which have an arm swing of 45 deg, are used as safety rods, other is control rod. Safety rods' action time is 0.5 sec, with any one safety rod able to shut down reactor.—Designer, General Nuclear Engineering Corp., Dunedin, Fla.; manufacturer, American Machine & Foundry Corp., 261 Madison Ave., New York 16, N. Y.

* * *

For more on the Argonaut reactor see NU, March '57, 62.

Reactor Control Instrumentatian

Designed specifically for use in a Naval reactor system, this instrumentation, when employed as integrated system, can provide complete monitoring of neutron level of any large power reactor. Individual components can be used to meet requirements of smaller power and research reactors. Low-neutron-flux equipment has two channels, each consisting of BF_3 neutron detector, detector power supply, and completely transistorized pulse-rate computer. Neutron pulses from detectors are transmitted over cable, which may be 300 ft from input of pulse amplifier. In the intermediate range equipment there are two channels, each with gamma compensated ionization chamber, ionization chamber power supply, and intermediate range computer. Power range equipment has channels operating into one shutdown circuit with each channel including uncompensated ionization chamber, power supply and power range computer.—Fairchild Camera & Instrument Corp., Syosset, N. Y.

RADIATION DETECTORS AND ACCESSORIES

Neutron Long Counter

Unit features subminiature preamplifier constructed into a BF_3 detector tube which allows detector assembly to operate 50 ft from electronic instruments without sensitivity loss. Neutron energy response is 100 kev–5.0 Mev; sensitivity from 560 cpm/n/sec/cm^2 for PoBe n flux.—Tullamore Electronics Laboratory, 6055 S. Ashland Ave., Chicago 36, Ill.

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Loading Face of BNL Research Reactor at
Brookhaven National Laboratory, Upton, N. Y.

New Brookhaven fuel element gives improved performance

Scientists and engineers of the Brookhaven National Laboratory have conceived a reactor fuel element of advanced design that promises to greatly improve the usefulness of the BNL Reactor.

The new design differs markedly from the one used originally when the Brookhaven reactor — the first large-scale research reactor in the United States — was put into operation in 1950.

The original fuel elements were natural uranium slugs, 4 in. by 1.1 in. in diameter, canned in finned aluminum tubes.

The improved two-foot element, shown above, is an assembly of three fuel plates which contain highly enriched (93%) uranium-aluminum alloy clad in aluminum. It is expected to afford these important advantages:

1. Higher neutron flux—an increase from the present 5×10^{13} up to 3×10^{14}.
2. Lower total reactor heat output — a reduction from 24 to 20 megawatts.
3. Less cooling air required—due to improved aerodynamic design of the enriched elements.
4. Higher fuel burn-up of contained U^{235}-up to 40% burn-up with enriched elements compared with 10% obtained with present natural uranium fuel.
5. Reduced reactor inventory of U^{235}-from 385 Kg contained in present fuel to 55 Kg in enriched elements.

With more than eight years' pioneering experience in the fabrication and development of all types of fuel elements, Sylvania-Corning Nuclear Corp. was chosen to supply several hundred test elements of the new design. These were installed in the central "hot spot" of the reactor for proving out.

Results have proven satisfactory and Brookhaven has decided to go ahead with the complete replacement program based on the new design. Sylvania-Corning Nuclear Corp. will supply the 5000 fuel elements needed.

Whether your own reactor is in actual operation, or merely in the planning stage, our scientific and engineering staff is ready to assist you, too, in achieving improved fuel performance. For your files, write for our booklet on Nuclear Fuel Elements.

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Portable Mass Spectrometer

Analyzing gaseous mixtures, or liquids being vaporized can now be solved with portable mass spectrometer using radio-frequency principle, modular design permits control unit to be separated from analyzer unit. Mass numbers appear linearly on motor-driven dial thereby making mass marking unnecessary. Mass range is 2–80. Weighs 115 lb.—Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

Ratemeter. Model CRM-11 is designed to power and to detect radioactivity sensed by G-M, scintillation and proportional counting detectors. Ratemeter is equipped with six linear scales, covering counting ranges from 0–300 cpm to 0–300,000 cpm. All tubes operate below 170° F.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Independent monitor. Model GA-3 will measure, display, record and control alarms for γ radiation from background (0.025 mr/hr) to 10^5/hr or higher in energy range from 80 kev to 1.5 Mev. System consists of control unit with meter relay, automatic reset, three- or six-decade log scale, calibration controls, etc. Unit is completely self-contained and battery operated. —Riggs Nucleonics Co., 2390 Olive Ave., Altadena, Calif.

Scintillation detectors. Models DS5-1 and DS5-1P, gamma-sensitive directional scintillation detectors, are useful for research or industrial applications where directional characteristics are important. DS5-1 is equipped with a 1-in.^{2} crystal while other model has 2-in.^{2} crystal. Both models may be

converted to α, β, or γ well-type scintillation detectors by substituting phosphors or crystals. Three collimators furnished with each instrument can be interchanged.—Nuclear-Chicago Corp., 223 W. Erie St., Chicago 10, Ill.

LABORATORY INSTRUMENTS AND APPARATUS

Thermal Console

Model 140-A provides an automatic system for determining accurately coefficient of thermal conductivity for insulating materials. Temperature 100° F–1400° F for hotplate control and guard heater; temperatures 60° F–600° F for cooling plate. Hot and cold surface temperatures obtained and maintained automatically within 1%. —Parameters, Inc., 195 Herricks Rd., New Hyde Park, N. Y.

Measures humidity. Remote indicator will measure humidity of closed areas; it can be located away from area being measured. Mechanical operations permit ±1.5% accuracy. Two connections are necessary—one from inlet at bottom of indicator to air line from container or area sampled, the other from outlet at top of case to vacuum pump or line. Sells for $175. —Serdex, Inc., 91 Cambridge St., Boston 14, Mass.

Leak detector. Model 4902 leaks <2 in^3 of gas/yr. Unit has neither pumps nor liquid nitrogen cold traps; costs $<\frac{1}{3}$ as much as mass spectrometer detector.—NRC Equipment Corp., 160 Charlemont St., Newton Highlands 61, Mass.

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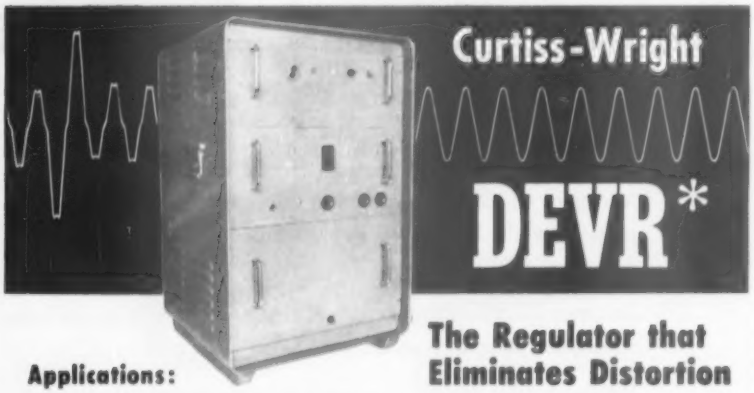

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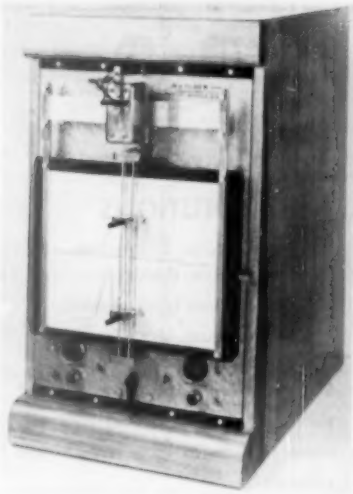
CONTROLLERS AND RECORDERS

Strip Chart Recorder

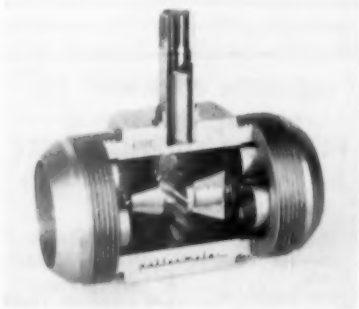
Model 601 can be used for integrating data from chart recordings of such process characteristics as flow, pressure, temperature, etc. Designed to accept chart up to $3\frac{7}{16}$ in. in size, with recorder handling 2 ft of chart in 15 sec.—Librascope, Inc., 808 Western Ave., Glendale, Calif.

Pressure transducer. Developed for use in data reduction systems, pressure transducer converts 3-15 psi signal to a-c millivolts directly proportional to pneumatic input. Accuracy of transducer is 0.25% of full scale.—Fischer & Porter Co., 93 Jacksonville Rd., Hatboro, Pa.



Two Pen Recorder

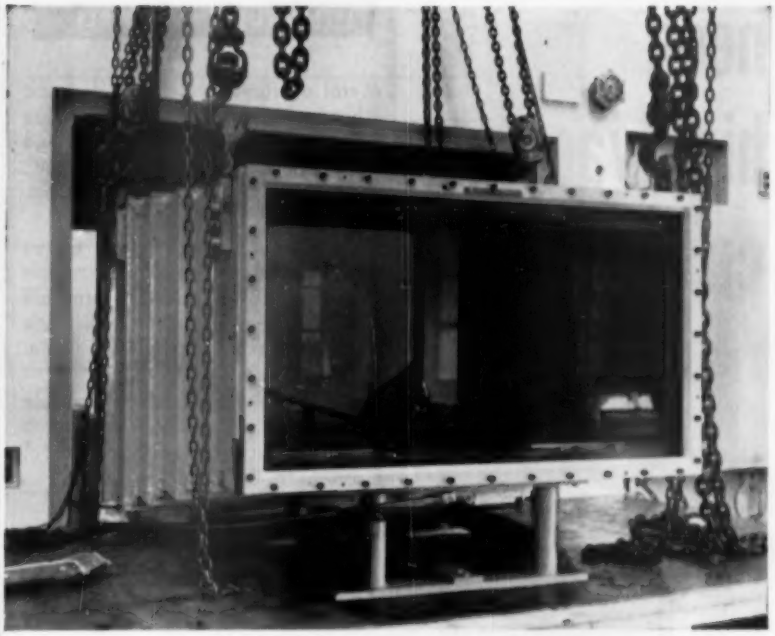
Model DAIR-107 is a two-pen recording-integrating densitometer designed for scanning paper electrophoretograms and chromatograms. One pen records curve as optical density, absorbence or percent transmission; other pen simultaneously plots true integral curve.—Matthew Laboratories, 146 Riverdale Ave., Yonkers, N. Y.



Flow Sensing Elements

This flowmeter (see cutaway view) meters high temperature and highly corrosive liquids at flow rates from $\frac{1}{10}$–10,000 gpm with accuracies ±5%. Meter has no bearings; also, no by-pass valve is necessary because nothing in meter will obstruct flow. Can be made of any non-magnetic material compatible with liquid to be measured.—Potter Aeronautical Corp., Union, N. J.

Self-balancing potentiometer. Transitorized, dual-pen, 5-in. strip-chart recorder provides correlation of measurements. Recorder's dimensions are 10 × 10 × 15 in. Sensitivity is 10 mv; linearity is within 0.5%.—Mt. Sopris Instrument Corp., 1320 Pearl St., Boulder, Colo.



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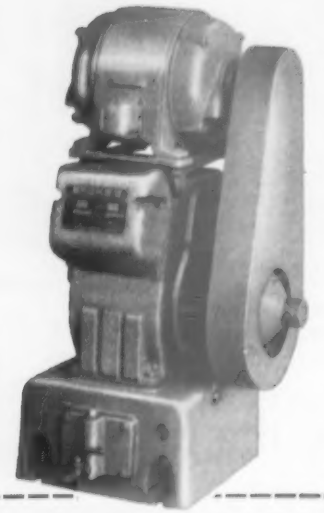

The Stokes Model 149 Microvac Pump has displacement of 70 cu. ft./min. . . . is a water-cooled unit. This pump cuts floor space requirements . . . measures less than 2 feet on a side. This model and all pumps in the Stokes Microvac line, 17-500 cfm capacity, are tested to produce vacuums of 10 microns or better on blank suction.

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LITERATURE AVAILABLE

Metal overlays to stainless steel and other ferritic base components to make them resistant to wear, corrosion and heat.—Cleveland Hard Facing, Inc., 3407 Stillson Ave., Cleveland 5, Ohio.

Wrought high-temperature alloys with physical properties, applications and shape availability in brochure DB-52-250.—Westinghouse Electric Corp., PO Box 2099, Pittsburgh 30, Pa.

High capacity gas thermostats in bulletin RT-813.—Robertshaw-Fulton Controls Co., 110 E. Otterman St., Greensburg, Pa.

G-M tubes and cathode ray tubes. 41 p.—20th Century Electronics, Dunbar Works, Dunbar Street, West Norwood, London SE 27, England.

High-vacuum equipment for laboratory and industrial applications. 23 p.—Consolidated Electrodynamics Corp., 1775 Mt. Read Blvd., Rochester, N. Y.

Selecting appropriate flow meter for specific application in bulletin 110.—Brooks Rotameter Co., Lansdale, Pa.

Engineered and manipulated components; production and testing zirconium tubes in reactors; techniques of joining beryllium; niobium fuel element sheaths, etc. 16 p.—Tube Investments Ltd., The Adelphia, London, W. C. 2, England.

Microwave tubes for communications, radar-navigation, severe environmental service and test-instrumentation. 31 p.—Varian Associates, 611 Hansen Way, Palo Alto, Calif.

"Radioactivity at Work," is first of series of pamphlets about firm's activities.—Nuclear Science & Engineering Corp., Pittsburgh 36, Pa.

Electrostatic machines with operational data, besides firm's comments on high voltage equipment. 35 p.—SAMES (Societe Anonyme de Machines Electrostatiques), Grenoble, France.

"Engineering for Atomic Power," shows firm's role in developing both military and industrial nuclear projects since 1942. 36 p.—Stone & Webster Engineering Corp., 49 Federal St., Boston, Mass.

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Filters and filtration systems for nuclear power and research. 6 p.—Cuno Engineering Corp., Meriden, Conn.

Linear variable differential transformers and their mechanical, electrical features. 19 p.—Schaevitz Engineering, PO Box 505, Camden 1, N. J.

Wide-band oscilloscope (model 411A) for general laboratory purpose.—Laboratory for Electronics, Inc., 75 Pitts St., Boston 14, Mass.

Semi-steel valve lines and their applications. 43 p.—Rockwell Mfg. Co., 400 N. Lexington Ave., Pittsburgh 8, Pa.

Induced-draft counterflow cooling towers. 32 p.—Foster Wheeler Corp., 165 Broadway, New York 6, N. Y.

Laboratory furniture and equipment. —Metalab Equipment Co., 282 Duffy Ave., Hicksville, N. Y.

Radiation detectors, radiochemicals and accessories with prices. 65 p.—Nuclear-Chicago Corp., 223 W. Erie St., Chicago 10, Ill.

Sonobraze is ultrasonic equipment for fluxless brazing and coating aluminum. —Aeroprojects, Inc., 310 E. Rosedale Ave., West Chester, Pa.

Press-I-Cell measures absolute gage or differential fluid pressures. 11 p.—Fischer & Porter Co., 99 Jacksonville Rd., Hatboro, Pa.

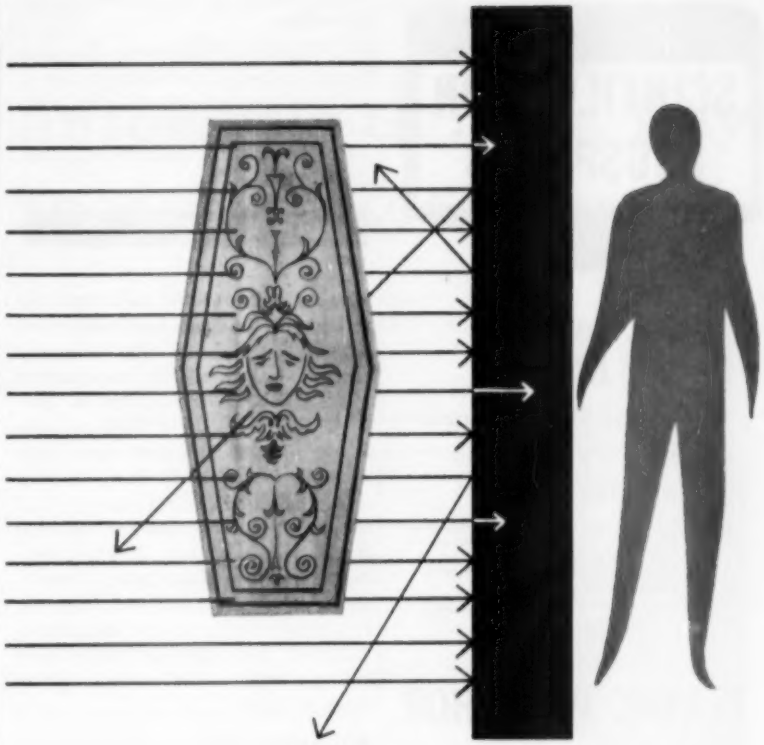
Radioisotope line with specifications listed in technical bulletin 14A.—Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

Zirconium bibliography lists properties of metal and its alloys—Columbia–National Corp., 70 Memorial Drive, Cambridge 42, Mass.

"Berkeley Engineering," New quarterly publication, contains features on electronic subjects plus company news. —Department 6348, Beckman/Berkeley Division, 2200 Wright Ave., Richmond, Calif.

Nuclear metallurgy services and facilities for research and development.—Metals Research & Development, Inc., Exeter, Pa.

Fume head engineering data, operating characteristics and cost comparisons. 48 p.—Kewaunee Mfg. Co., 5083 S. Center St., Adrian, Mich.



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Correction

Data sheet 54–23 specifically discusses linearity tolerances of Series D and E potentiometers not potentiometers generally as reported in NU, June '57, 151. —Helipot Corp., Newport Beach, Calif.

INDUSTRY NOTES

▶**Beckman Instruments** has formed the systems division to manufacture and sell automatic process monitoring and control systems. With headquarters and manufacturing facilities at Anaheim, Calif., besides a plant in Richmond, the new division consolidates activities of two other Berkeley divisions—scientific instruments and Berkeley. John F. Bishop will head this division, with T. C. Fletcher, engineering and manufacturing director, and W. E. Rianda, marketing director. In another Beckman staff assignment, Robert J. Baumann was named marketing director of the scientific instruments division.

▶**Tracerlab** has named Thomas L. Kelley nuclear sales manager. He was previously instrument division sales manager.

▶**Robertshaw-Fulton Controls Co.** will move its executive offices this fall from Greensburg, Pa., to Richmond, Va.

▶A new firm, **Eastern Technical Associates,** Hastings-on-Hudson, N. Y. will offer consulting services in such fields as atomic and molecular beams, radiation physics and gas discharges.

▶**Texas Nuclear Corp.,** Austin, newly-organized firm offers physics research and consulting services. A 2-Mev positive-ion accelerator was installed as the firm's primary research tool.

▶**Fischer & Porter Co.** has promoted Robert L. Rice to general sales manager.

▶**Packard Instrument Co.,** La Grange, Ill. has incorporated after operating since its founding in 1949 as a sole proprietorship. Lyle E. Packard is president; William S. Scott is vice-president.

▶**Isotopes Developments Ltd.,** Aldermaston, England, has appointed E. W. Jones to be sales manager.

▶**Laboratories Derveaux,** Boulogne, France, was named exclusive French representatives for Aerojet-General Nucleonics' 201 reactor.

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Venice Conference

(*Continued from p. 89*)

to account for the neutrons observed. The effect would be seen in the external circuit by voltage spikes which are, in fact, observed and which have been observed in a few cases by the Aldermaston group. Since $m = 0$ instabilities would be eliminated by a longitudinal magnetic field, such a field should, therefore, quench the neutron production. This has been experimentally confirmed in the Livermore work so the difference between the mechanisms operating in the Livermore and Aldermaston experiments is evident. It should, however, be remembered that the yield in the Aldermaston work is down from the Livermore results by a factor of 10^3 and it was not clear what the minimum detectability for neutrons in the Livermore experiments was.

Fusion in Russia

Although the Russians who attended the conference were prepared for formal presentations on subject matter relating only remotely to thermonuclear problems (about the closest thing were papers by N. V. Fedeorenko on charge exchange collisions), they did present an unscheduled paper on the gross stability of magneto-hydrodynamic equilibrium configurations. This paper was read by Schafranov. Although this was their only official contribution the five or six Russians at the conference acted as very interested observers and were eager to enter into the informal discussions. It should be further remembered that it was the Russians who initially led the declassified literature in the field—first by Kurchatov at Harwell—and later (with still no response from the U. S. and U. K.) at the Stockholm Conference last year.

As to the current status of the Russian effort the following inferences can be drawn from the conference:

1. A proven controlled thermonuclear reaction has probably *not* been achieved in Russia.
2. Their program is sufficiently large so that their degree of technical familiarity with the topic is equivalent to ours. (The actual size of their project could not be revealed.)

Everyone—including the Russians—expressed the general hope that controlled fusion research would be declassified within the year.

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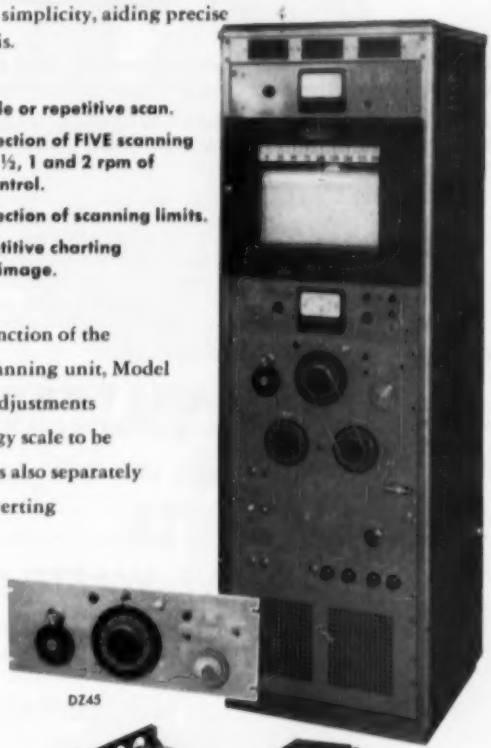

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NEWSMAKERS

Marvin Fox has joined Internuclear Co. as project manager on a nuclear power plant to be built for Societá Elettronucleare Nazionale (SENN) in southern Italy (NU, June '57, 27).

Fox had been chairman of Brookhaven National Laboratory's reactor division, where he headed operations of the research reactor since its completion in 1950. Last year Fox led a State Department–International Cooperation Administration team studying a nuclear research center in Manila for Colombo Plan countries, and was a consultant to AEC's advisory committee on reactor safeguards. Succeeding to Fox's BNL post is **Robert Powell,** former head of the reactor operations division.

National Lead Co. has appointed **George W. Wunder** vice-president and manager of the newly formed nuclear metals division. In his new post, he becomes general manager of subsidiaries operating AEC installations at Fernald, O.; Winchester, Mass.; Grand Junction, Colo.; and Monticello, Wash. He also becomes director of research-development on commercial and industrial applications of nuclear products and director of his firm's activities in the Industrial Reactor Laboratories project (NU, Oct. '56, R5; March '57, R9). Succeeding to Wunder's previous position as manager of the Fernald-AEC site is **James H. Noyes,** assistant plant manager.

In England, **H. A. Luss** was appointed chairman of the nucleonics group of the Scientific Instrument Makers' Association. He is joint managing director of Isotope Developments Ltd.

Cook Electric's Inland Testing Laboratories named **Miguel A. Xavier** technical director, and **Howard B. Van Dagens** assistant technical director.

Harvey Brooks will become dean of engineering and applied physics at

Harvard Univ. on Sept. 1, succeeding **John H. Van Vleck,** who plans to resume research in mathematical physics.

Leslie L. Smith has joined the central research group of the Nuclear Corporation of America, New York. He had been engaged on dosimetry problems with the nuclear research group of Convair, Fort Worth, Tex.

Marian Balicki has joined the staff of Sylvania-Corning Nuclear Corp.'s department of physical metallurgy and ceramics. He had been head of the metallurgical engineering division at the Polytechnic Institute of Brooklyn.

Joining General Atomic's Hopkins Laboratory are physicists **Charles C. Loomis,** from Los Alamos, **Charles L. Oxley,** from Univ. of Chicago; **Mark S. Nelkin,** from Knolls Atomic Power Laboratory, **Brian Dunne,** from Univ. of Calif. in Los Angeles; and **Reid D. Carlson,** from Navy Electronics Laboratory. Also, **John H. Cawley,** electrical engineer, from Scripps Institution of Oceanography; mechanical engineer **William A. Compton,** from Thompson Products; and **Robert G. Fischer,** aeronautical engineer, from Atomics International.

Oak Ridge Institute of Nuclear Studies has selected **Arthur L. Schipper** to be assistant in the university relations division. He is a former Notre Dame biologist.

American Nuclear Society's newly formed Northeastern New York section has nominated **W. R. Kanne** of Knolls Atomic Power Laboratory to be chairman, and **V. L. Parsegian** of Rensselaer Polytechnic Institute, vice-chairman.

Frederick R. Einsidler has been named manager of AMF's engineering laboratory in Brooklyn, N. Y.

Promoted at Mallinckrodt Chemical Works are **William B. Burford III,** to director of inorganic research; **Charles O. Gerfen,** to assistant director of inorganic research; and **John A. Caughlan,** to assistant director of industrial chemicals product development.

Theodore T. Magel will fill the newly-established post of assistant to the vice-president and technical director of Allegheny Ludlum Steel. Previously with Nuclear Metals, he will be responsible for Allegheny's nuclear materials development program.

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NUCLEAR CALENDAR

Aug. 19–24—High-energy physics symposium, Oak Ridge National Laboratory and Institute of Nuclear Studies. Topics include theory of elementary particles and their interactions, experiments with nuclear-emulsion techniques, bubble chambers and counters. Contact University Relations Division, ORINS, P.O. Box 117, Oak Ridge, Tenn.

Aug. 20–21—Third biennial electron beam symposium, General Electric X-ray dept., Milwaukee. Reports on radiation equipment, applications and economic evaluation of processes in chemicals, plastics, petroleum and food fields. Contact J. J. Ludwig, GE X-ray dept., 4855 Electric Ave., Milwaukee 1.

Aug. 20–22—Conference on liquid scintillation counting, Northwestern Univ., at Technological Institute, Evanston, Ill. Coincidence counters, single-channel counters, chemistry of liquid scintillators, applications in biology, medicine, industry, archaeology, physics, chemistry and engineering. Contact F. Newton Hayes, Los Alamos, N. M.

Aug. 28–30—Pacific general meeting, AIEE, Richland, Wash. Sessions include nucleonics; nucleonic and radiation instruments; industrial power systems; safety. Contact R. C. Hoffman, 1323 Kimball Ave., Richland.

Sept. 8–13—Conference on water purity requirements and water conditioning equipment of nuclear power plants. American Chemical Society, New York. Contact ACS, 2 Park Ave., New York 16, N. Y.

Sept. 8–21—Second European atomic energy course for management, Knokke, Belgium (*La Réserve*). Contact R. M. Ballinger, P.O. Box 169, Paris 16, France.

Sept. 9–13—Twelfth annual Instrument-Automation conference and exhibit, ISA, Cleveland (*Cleveland Auditorium*). Contact H. S. Kindler, ISA, 313 Sixth Ave., Pittsburgh 22, Pa.

Sept. 9–13—International conference on nuclear structure, co-sponsored by Unesco and International Union of Pure and Applied Physics, at Rehovoth, Israel. Contact Amos de Shalit, nuclear physics department, Weizmann Institute of Science, Rehovoth.

Sept. 9–13—International conference on neutron interactions with the nucleus, Columbia Univ., New York. Participants include I. I. Rabi, W. B. Lewis, H. A. Bethe, D. J. Hughes, E. P. Wigner. Contact R. W. Siegel, Physics dept., Columbia Univ., New York 27.

Sept. 9–20—International conference on radioisotopes in scientific research, Unesco, in Paris. Purpose: exposition and discussion of new ideas or methods for utilization of radioisotopes in scientific research. Plenary sessions on production and measurement techniques, section meetings in physical and biological applications. Contact Dept. of Natural Sciences, Unesco, 19 Avenue Kléber, Paris 8e.

Sept. 22–27—Colloquium on mesons and recently-discovered particles, International Union of Pure and Applied Physics, in Venice. Contact Prof. Eligio Perucca, director, Politecnico, Turin, Italy.

Oct. 6–12—Ninth atomic energy course for management, National Industrial Conference Board, in Chicago (*Hotel Moraine-on-the-Lake*), Highland Park, Ill. Contact John McMahon, NICB, 460 Park Ave., NYC.

Oct. 7–9—Thirteenth annual National Electronics Conference, Chicago (*Sherman*). 100 technical papers, 240 exhibits. Contact F. A. Judd, NEC, 84 E. Randolph St., Chicago 1.

Oct. 7–12—French Metallurgical Week, French Metallurgical Society, Paris. Contact J. Pomey, president FMS, 25 rue de Clichy, Paris 9.

Oct. 28–Nov. 1—Autumn Nuclear Week in New York. Included are: **28–30th**, fourth annual meeting of the Atomic Industrial Forum (meetings *Plaza* and *Coliseum;* banquet *Waldorf*). **28–31st**, third annual Trade Fair of the Atomic Industry, sponsored by AIF (*Coliseum*). **28–30th** second winter meeting of the American Nuclear Society (*Henry Hudson*). **31st**, AEC-ANS-AIF reactor safety conference. And IRE's Professional Group on Nuclear Science holds fourth annual meeting **31–1st** (*Henry Hudson*).

Nov. 2–8—Second world metallurgical congress, American Society for Metals, Chicago. Contact W. H. Eisenman, congress secretary general, ASM, Cleveland. **3–8th**, second international conference on nondestructive testing. Contact G. H. Tenney, 704 47th St., Los Alamos, N. M.

Nov. 7–8—Seventh annual symposium, Philadelphia section of Instrument Society of America, Philadelphia (*Sheraton*). Subject: new ideas in instrumentation evolved from nuclear developments. Instruments Fair included. Contact Warren Brand, Conoflow Corp., 2100 Arch St., Philadelphia 3.

Dec. 24–26—Conference on nuclear sizes and density distribution, National Science Foundation, Palo Alto, Calif. Contact Robert Hofstadter, Stanford Univ., Palo Alto.

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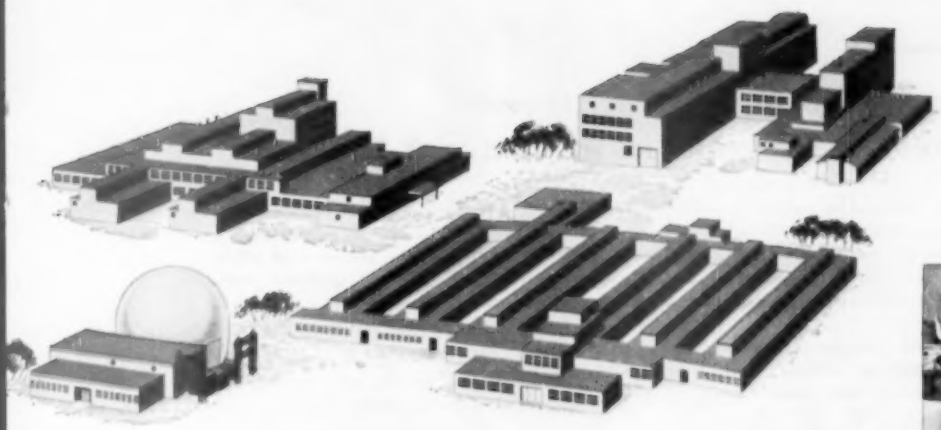

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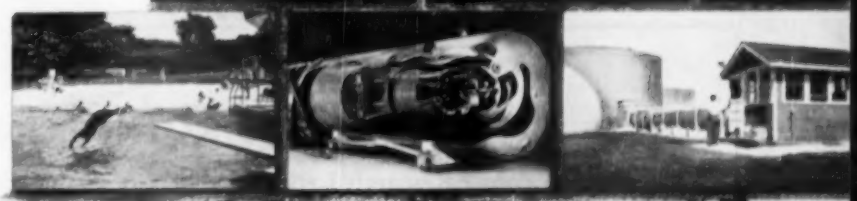

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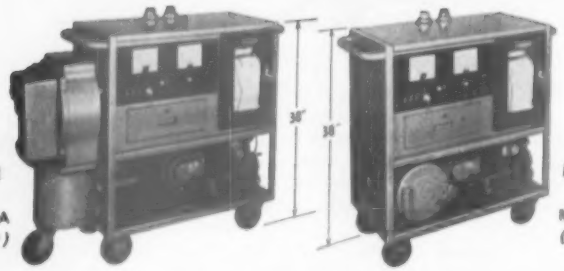

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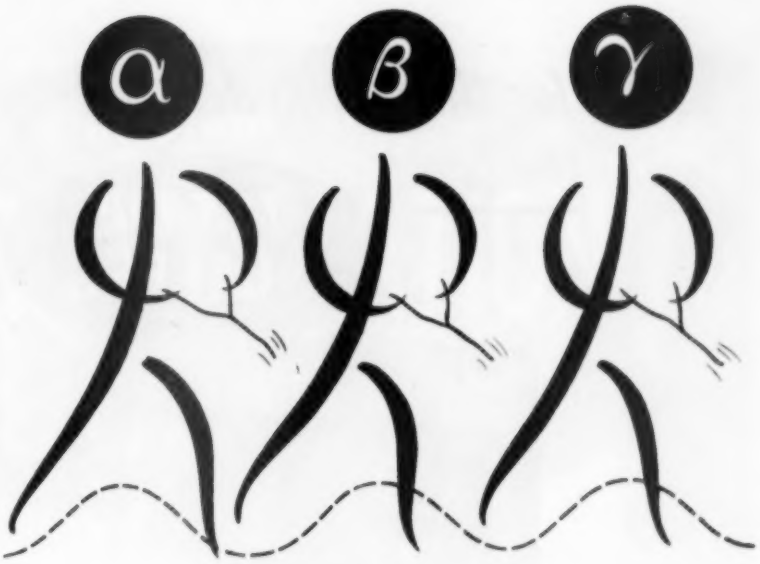

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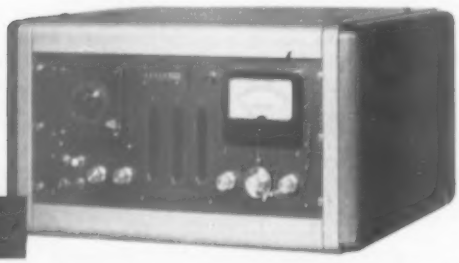

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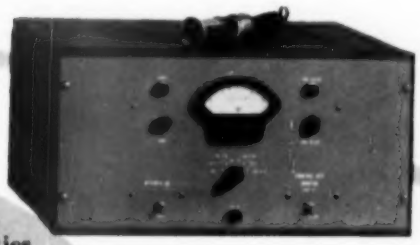

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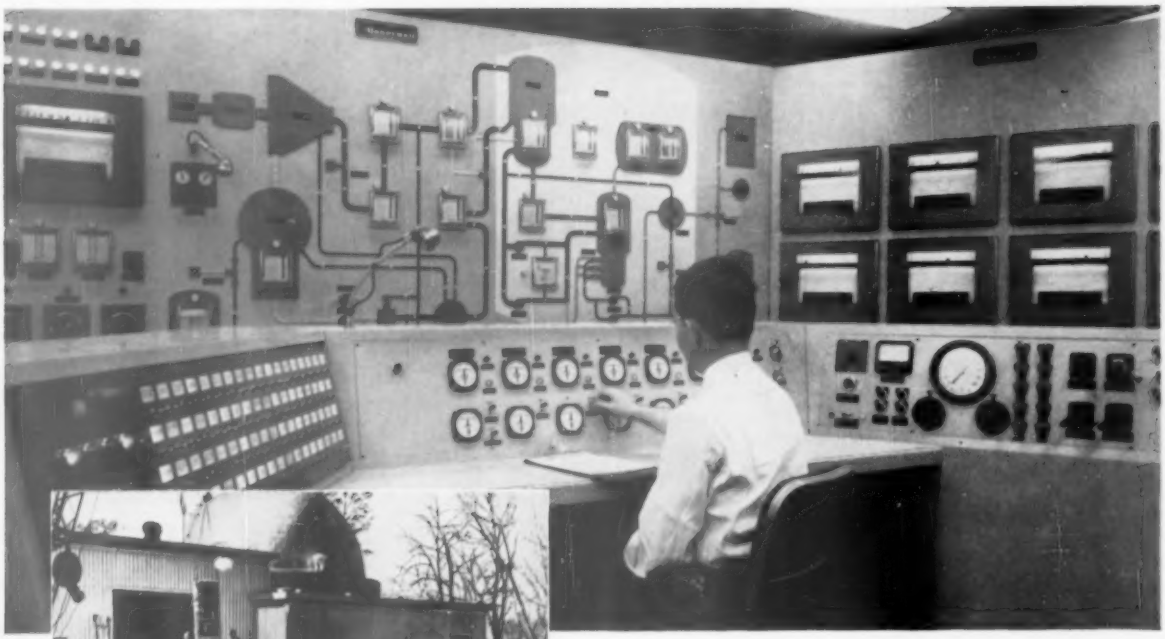
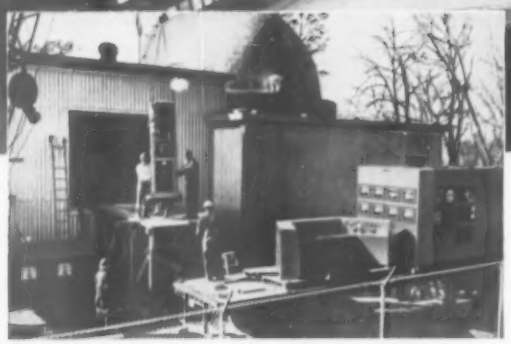


An ALCO Products atomic engineer operates the Army Package Power Reactor at a Honeywell control console.



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